PROCEEDINGS
THE INSTITUTION OF CIVIL ENGINEERS

PART I
NOVEMBER 1953

ORDINARY MEETING

21 April, 1953

HENRY FRANCIS CRONIN, C.B.E., M.C., B.Sc.(Eng.), President, in the Chair

The President, the members present standing, read the following resolutions of condolence which had been passed by the council at their meeting that afternoon:

"That the Council record the deep regret with which they have learned of the death of Sir David Anderson, LL.D., B.Sc., Past President of the Institution, who was a member of the Institution for 47 years, and served on the Council for 17 years. He was elected a Vice-President in November, 1940, and President in November, 1943.

"The Council desire that an expression of their sincere sympathy be conveyed to the members of his family in their bereavement."

"That the Council record the deep regret with which they have learned of the tragic and untimely death of their former colleague Dr Guthlac Wilson, S.M., in a recent air accident in East Africa. He was elected a Member of the Council in November, 1949.

"The Council desire to convey their sincere condolences to the members of his family."

It was resolved :—

"That Messrs H. M. Bostandji, D. A. Brown, E. W. Cuthbert, R. W. A. Fane, Andrew Henderson, E. C. Lightbody, C. W. Pike, and H. Ridehalgh, be appointed to act as Scrutineers, in accordance with the By-laws, of the Ballot for the election of the Council for the year 1953–1954."

The Council reported that they had recently transferred to the class of

Members

BLUMFIELD, CYRIL VERNON, B.Sc.(Eng.) (*London*).
COLEBROOK, CYRIL FRANK, T.D., Ph.D. (*London*), B.Sc.(Eng.) (*London*).
ELLIOTT, DONALD GEORGE, B.Sc. (*Edinburgh*).
ETCHES, FRANK GEORGE, B.Sc.(Eng.) (*London*).
ETTERSHANK, LEONARD.
FRAMPTON, VYVYAN WINSTANLEY, B.Sc. (Eng.) (*London*).
HAWORTH, WILLIAM DOUGLAS.
HUMPHRIES, JOHN HOWARD, B.Sc.(Eng.) (*London*).
MACNICOL, COLIN ARCHIBALD, B.Sc. (*Durham*).
ROWE, OLIVER CYRIL.
STOW, GEORGE, O.B.E.
WATSON, JOHN HEDEN JOSEPH.
WILKES, JOHN HUMPHREY HARRY, B.Sc. (Eng.) (*London*).

and had admitted as

Graduates

AAB, ARNOLD FRIEDRICH, B.Sc. (*Witwatersrand*).
ACKERS, GODFREY LLOYD, M.A. (*Oxon.*), Stud.I.C.E.
ALAGIAH, DONALD RATNARAJAH.
ALLEN, CHARLES DAVID, B.Sc.(Eng.) (*London*).
ALPE, GRAHAM, B.Sc.(Eng.) (*London*).
BARKER, MICHAEL CROSBY, B.Sc.(Eng.) (*London*), Stud.I.C.E.
BARRETT, KENNETH, Stud.I.C.E.
BISH, MAXWELL EDWARD, B.E. (*New Zealand*).
BOAK, JOHN ALAN TYSON, B.A. (*Cantab.*), Stud.I.C.E.
BRAZIER, ALAN, Stud.I.C.E.
BROWN, JOHN CRAIG, B.Sc. (*St Andrews*).
CHAPMAN, JOHN, B.Sc.(Eng.) (*London*).
CLAGUE, EDWARD JAMES, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
DOBSON, JAMES FRANCIS, B.Sc.(Eng.) (*London*), Stud.I.C.E.
DOE, PETER WILLIAM, B.Sc. (*Manchester*), Stud.I.C.E.
ELLIOT, ROBIN COLLARD, B.E. (*W. Australia*).
FOSTER, FREDERICK CHARLES, B.Sc. (Eng.) (*London*), Stud.I.C.E.
FRIEND, HENRY RALPH, B.A. (*Cantab.*).
GADD, WILLIAM GEORGE, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
GARDNER, JOHN DAVID WALKER, B.Sc. Tech. (*Manchester*).
GARDNER, ROGER WHITESIDE, B.Sc. (Eng.) (*London*), Stud.I.C.E.
GLOVER, EDWARD FRANCIS, B.A. (*Cantab.*).
GODDEN, HAROLD CLARKE, B.A., B.A.I. (*Dublin*).
GOODYEAR, ALAN STEWART, B.E. (*New Zealand.*)
HAMILTON, ALEXANDER MCEWAN DOUGLAS.
HANCOCK, PETER HENRY DRUMMOND, B.A. (*Cantab.*), Stud.I.C.E.
HARBOROW, WILLIAM EUSTICE, B.Sc. (*Nottingham*), Stud.I.C.E.
HARRIS, JOHN ARTHUR, B.Eng. (*Sheffield*), Stud.I.C.E.
HEELEY, JOHN CHARLES, B.Sc.(Eng.) (*London*).
HOAD, VIVIAN JOHN WILLIAM, B.Sc. (Eng.) (*London*), Stud.I.C.E.
HOSSACK, ADAM WILKIE, B.Sc. (*Edinburgh*),
HUME, ERIC WILLIAM, Stud.I.C.E.
INKSON, DOUGLAS NORMAN, B.Sc. (*Belfast*), Stud.I.C.E.
JAMES, PETER RICHARD, Stud.I.C.E.
JAMIESON, JAMES WILLIAM, B.Sc.(Eng.) (*London*), Stud.I.C.E.
JOHNSON, WILLIAM MARTIN, B.Eng. (*Liverpool*), Stud.I.C.E.
JORDAN, ROBERT WILLIAM, B.Sc.(Eng.) (*London*), Stud.I.C.E.
JULIAN, LEONARD WILLIAM, B.Sc.(Eng.) (*London*).
KEARNEY, PETER ANTHONY, Stud.I.C.E.
KULATUNGA, VIJITA SIRISENA, B.Sc. (Eng.) (*London*), Stud.I.C.E.
LAMBERT, DEREK MYERS, B.Sc.(Eng.) (*London*), Stud.I.C.E.
LARNACH, WILLIAM JOB, M.Sc. (*Durham*), Stud.I.C.E.
LIDDLE, JOHN BRIGHAM, B.Sc. (*Glasgow*).
LYLE, WILLIAM HENRY KEWLEY, M.A., B.Sc. (*Edinburgh*).
LYNCH, VICTOR JOHN.
LYNDON, ALFRED, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
MARSDEN, ALBERT, Stud.I.C.E.

MARSHALL, ALAN ARTHUR JAMES, Stud.I.C.E.
MARTIN, JOHN NEVILLE, Stud.I.C.E.
MOIR, ROBERT KEITH, B.E. (*New Zealand*).
MORICE, PETER BEAUMONT, B.Sc. (*Bristol*), Stud.I.C.E.
MOSS, JOHN DIDSBURY, B.E. (*New Zealand*).
NEWELL, JOHN DAVID, B.Sc.(Eng.) (*London*).
NORMAN, KEITH JACK, B.Sc.(Eng.) (*London*), Stud.I.C.E.
O'KEEFFE, JOHN DECLAN, B.E. (*National*).
PATHMANATHAN, SABHARATNAM, B.Sc. (Eng.) (*London*).
PENDAL, BRYAN JAMES, B.Sc.(Eng.) (*London*), Stud.I.C.E.
PERERA, MAKEVITAGE GRAHAM CECIL, B.Sc.(Eng.) (*London*).
PROVAN, ARCHIBALD DOUGLAS HART, B.Sc.(*St Andrews*), Stud.I.C.E.
RATNESER, BALACHANDRA DHARMARAJAH, B.Sc.(Eng.) (*London*), Stud.I.C.E.
REA, GUY SAMUEL PATTERSON, B.Sc. (*Belfast*), Stud.I.C.E.
RICHARDSON, JAMES WILLIAM ROBERT, B.A. (*Cantab.*), Stud.I.C.E.
ROBERTS, MICHAEL GROVES, B.A. (*Cantab.*), Stud.I.C.E.
ROE, JOHN, B.E. (*Queensland*).
ROWLAND, VERNON ROY, B.Sc. (*Bristol*), Stud.I.C.E.
SARGENT, MURRAY REID, Stud.I.C.E.
SCHNEIDER, SAUL JACOB, B.Sc. (*Cape Town*), Stud.I.C.E.
SELLEK, JOHN WALTER, Stud.I.C.E.
SILGARDO, MERVYN BERNARD, B.Sc. Tech. (*Manchester*).
SMITH, LIONEL FREDERICK, B.Sc.(Eng.) (*London*), Stud.I.C.E.
SPRINGSGUTH, ALAN GRIFFITH, B.Sc. (*Wales*), Stud.I.C.E.
STODDART, JAMES, B.Sc. (*Glasgow*), Stud.I.C.E.
WAKELY, PETER HILDITCH, B.A. (*Cantab.*).
WALDEN, JOHN GRAHAM, Stud.I.C.E.
WEST, MICHAEL JOHN HAWTREY, B.Sc. (Eng.) (*London*), Stud.I.C.E.
WHORRALL, LAWRENCE VICTOR, B.Sc. (*Manchester*).
WILLIAMS, GEOFFREY THEO, B.Sc. (*Bristol*), Stud.I.C.E.
WORMALD, PETER SHAW, M.Sc. (*Leeds*), Stud.I.C.E.
WRIGHT, GORDON STANLEY, B.Sc.(Eng.) (*London*).

and had admitted as

Students

AADNESEN, LARS.
ALDERTON, ARTHUR FRANCIS.
ALEMAYEHU, HAILU.
ASHWORTH, ROBERT.
ATKINSON, CHARLES HARRISON.
ATTWOOD, JOHN HARRY.
BARLOW, GEOFFREY SAMUEL.
BELOW, MARTIN.
BENNEY, JOHN HARVEY.
BOOTH, JOHN.
BOTT, RAYMOND LEONARD.
BRADY, ANTHONY JOHN STUART.
BRIERLEY, ANTHONY WASHINGTON.
BROWN, COLIN BERTRAM.
BUTCHER, DONALD BERNARD.
CARR, ROBERT WILLIAM.
CARROLL, LEO JOSEPH.
CHALCRAFT, TERENCE JAMES.
CHAN, WILLIAM WAI-LEE, B.Sc. (*Hong Kong*).
CHAPMAN, COLIN LEONARD.
COANE, ANTHONY MARK.
COLLINS, DAVID THOMAS.
COOPER, MICHAEL LLOYD.
CORNELL, HAROLD.
COURT, CHRISTOPHER DAVID.
CRICHTON, THOMAS BRYAN.
CROSSLEY, DEREK JOHN.
DEARDEN, OLIVER.
DICK, THOMAS MILNE.
DICKENS, WILLIAM RICHMOND.
DONALD, IAN WATSON.
DYSON, JOHN HIRST.
EDWARDS, DAVID EMYLN.
ELLIOTT, DOUGLAS ROBERTS.
ELLISON, ERNEST GRAHAM.
EVANS, ALAN.
EXELBY, RICHARD EDMUND.
FARRAR, RICHARD EDMUND SCRUTON.
FIELD, RICHARD NORMAN.
FISHER, ROGER.
FORDHAM, JOHN ANTHONY.
FOX, DENNIS.
GRIFFIN, ERIC FRANK.
GRIMER, FRANCIS JOSEPH.
HALLETT, REX.
HANCOCK, DONALD BRIAN.
HATHERELL, JOHN WATTS.
HEMSLEY, TONY.
HOGG, BRIAN GEORGE.
HOGGAN, JAMES IMRIE.
HOLLINS, ROGER MANSEL.
HOOK, DAVID MORGAN ALFRED.
HOYLAND, GEORGE ANTHONY.

Hume, Kenneth.
Hummel, Berthold Hermann.
Jeffery, Ernest Michael.
Johnston, David Robert.
King, Michael Dexter.
Kirkor, Andrzej.
Lawrence, Michael Edward.
Leather, Donald.
Lee, Peter William.
Leslie, Alan.
Lomax, William Reginald.
Lowth, Gerald Simon.
Mackereth, Peter Edward.
Marker, Soli Erach.
Marsden, Antony Ernest.
Mensah, John Dede.
Morriss, Alfred Harold.
Munnion, Keith Stuart.
Neave, George Neilson.
Nisbet, Richard Frederick.
Oppen, Richard Anthony.
Owen, Reginald St. John.
Pearson, Geoffrey.
Plucker, Guy Charles Leon.
Rossington, Douglas Turton.
Rule, John Reginald.
Slaughter, Colin Duncan.
Smith, John Edward.
Speirs, Gordon Stirling.
Spelman, Kenneth John.
Stainsby, Derek.
Steele, Alan Joseph.
Talbott, Thomas Adnitt.
Taylor, Gerald Edward.
Taylor, Neil.
Temperley, Eric Malcolm.
Thomas, Edward John.
Toal, Alexander Wright.
Tolfree, Richard Mortimer
Walters, John.
Whyatt, Philip Gilbert.
Williams, Fred Trevor.
Woolley, Malcolm Victor.

The following Paper was presented for discussion and, on the motion of the President, the thanks of the Institution were accorded to the Author.

Paper No. 5942

"Wood Preservation" *

by

Norman Arthur Richardson, B.Sc.†

SYNOPSIS

Under certain conditions, wood is subject to various forms of deterioration brought about by fungi, insects, or marine borers. Fungal decay is probably responsible for most of the damage to timber in Britain, and the conditions under which it occurs are clearly defined. Wood-destroying fungi require both air and moisture for their development. Properly seasoned wood is too dry for fungal attack and if it can be kept dry it will not be subject to decay. It is often possible, by suitable design, to ensure that timber will remain dry in use, but where this cannot be done it is necessary either to employ woods having a high natural resistance to decay or to treat the timber with a substance toxic to fungi. These materials are known as wood preservatives and they are of three main types, namely, oil, water-soluble, and solvent types, each of which has properties that determine their suitability for different uses of timber.

Timbers also differ in their resistance to attack by insects and marine borers, and can be protected against these forms of attack by impregnation with similar preservatives.

The method by which wood preservatives are applied is often even more important than the choice of the preservative. Surface treatments are of only very limited value and the best results are obtained by the use of impregnation treatments.

For sea-water structures good treatment is particularly necessary and in this connexion the use of round piling has distinct advantages, for it is often possible to make use of a permeable band of sapwood to obtain deep and uniform penetration of the creosote.

INTRODUCTION

CONSIDERING that wood is one of the oldest building materials, it is surprising that until recent years much less was known about its physical properties than of those of more modern ones such as steel and concrete. Even today, many architects and engineers only make use of data on the strength properties of timber when designing structures and do not give sufficient, if any, attention to the equally important question of durability. This is especially true of some engineers responsible for the installation of railway track, transmission poles, and marine structures which often fail prematurely through proper attention not having been given to the preservation of the timber.

The Institution of Civil Engineers has for many years taken an active

† Associate Roy. Inst. Chem.

interest in the subject of marine structures through its Sea Action Committees, but even so, far too much non-preserved or inadequately preserved timber is still being used in sea-water structures. Engineers in Great Britain traditionally make use of squared timber piling, but if the subject of durability were better understood and appreciated no doubt greater use would be made of round piling, as is done in most other parts of the world. (*Figs 1.*) If round timbers were used they could be satisfactorily creosoted very much more easily and would, as a result, give much longer service than is now obtained from piling around the coast of Britain. It is also true to say that a longer life could be obtained from many of the railway sleepers and electricity transmission poles used in Britain if more consideration were given to their preservation.

The use of the term " wood preservation " could imply that wood is not generally durable, but this is not so. Wood itself is an inherently stable material and, under favourable conditions, will last almost indefinitely. Under certain circumstances, however, it is subject to deterioration, sometimes very rapid, through biological, physical, mechanical, or chemical causes. This has been realized from the earliest times and numerous substances have been suggested from time to time for preserving it against these various forms of attack. It is, however, only during the past 100 years or so that the art of wood preservation has been developed and become an important industry in most parts of the world. Although the term " wood preservation " is sometimes used to describe methods by which the natural resistance of wood to all forms of deterioration can be improved, it is usually restricted to preservation against biological attack.

Biological and Other Forms of Attack

Biological attack includes that brought about by certain fungi, insects, and marine-boring animals. Some timbers have a high natural resistance to these and as a result have been used traditionally for structures where the conditions are favourable to depredation from these causes, and where durability is of primary importance. These highly durable woods, such as teak, greenheart, pitch pine, etc., have in the course of time become increasingly scarce, but even if this had not been so the amount of timber used under conditions favouring decay is greatly in excess of that which can be obtained from the naturally durable species. The need for preserving some of the less durable woods has become, therefore, increasingly important. It is indeed difficult to vizualize how the railway, telephone, and electricity undertakings in all parts of the world could have expanded to present-day standards had not some effective form of preservative treatment of wood been adopted for the vast amounts of timber consumed by these organizations. It is certain that sufficient timber would not have been available to meet the need of replacements of untreated poles and sleepers. Although alternative materials might have been employed for

these, it must be remembered that for many purposes wood is an ideal material, and the notable developments in rapid communication and land travel during the past 100 years have in no small measure been made possible by the use of preserved timber.

Fungal Attack (*see Fig. 2*)

Probably the most common cause of deterioration of timber in service is decay brought about by wood-destroying fungi. The conditions under which these fungi can feed on and destroy timber are well known and understood nowadays, and this knowledge can often be applied with advantage in practice to ensure that timber is employed in the best possible manner. Wood-destroying fungi derive their nourishment from wood and other cellulose-containing materials at ordinary temperatures, but they cannot function without oxygen (air) and moisture being present at the same time. This is an important fact to bear in mind when using wood, since it is often possible, by constructional or other means, to ensure that these conditions do not obtain. Timber that can be kept out of contact with air, or thoroughly dry, will not be subject to fungal decay and, although the occasions when timber can be used in these ways are limited, there are many examples of the long life obtainable from timber in its natural state under these conditions. Thus wooden water-pipes completely buried in the ground, or piling completely submerged in fresh water—that is, out of contact with air—have been recovered in a sound condition after several hundred years, even though the timbers used were those that would have decayed within a few years if used where both air and water were present at the same time. Furniture provides another example, for even when this is made of non-durable species, such as beech, it will remain free from decay indefinitely if maintained in too dry a condition for fungal attack. Good building practice takes these factors into account. Properly seasoned timber that can be prevented, by means of good ventilation and effective damp-proof courses, from picking up sufficient moisture from the ground or air will not be subject to decay. (*Fig. 6.*)

The term " seasoning " is used to describe the drying of timber, whether naturally in air or by the use of artificial methods involving the use of drying kilns. When a tree is felled and converted into lumber this has a high moisture content (from 50 to 200 per cent), and if the lumber is suitably piled so that air can freely circulate around it, it will gradually dry until the moisture content is reduced to about 15 to 18 per cent according to the temperature and humidity of the air. This natural drying of timber is known as air-seasoning and it should be noted that timber that has been properly air-seasoned is too dry for it to be subject to fungal attack, and it will remain immune so long as it is prevented from picking up moisture from rain or other sources. It should be recognized, however, that wood is hygroscopic, and dry wood can also absorb moisture from a damp atmosphere. Paints and varnishes, which are not toxic to wood-destroying

fungi, have some value in protecting wood against decay by providing a mechanical barrier against fungal spores that are always present in the air and by reducing the absorption of moisture, but their value lies in protecting timber that is subjected to moist conditions only for relatively short periods and against so-called "weathering" caused by shrinking and swelling of the surface layers of the wood under alternating wet and dry conditions.

When timber is used where it will naturally assume a moisture content exceeding 20 per cent, such as through being in contact with the ground, it will decay, and this can be conveniently prevented by impregnating the wood with a substance poisonous to fungi. This is the basis of the most widely applied method of preservation and experience has shown that when properly carried out it is a very satisfactory one. For example, Baltic redwood telephone poles, pressure-creosoted in 1870, were still in excellent condition more than 70 years later, and many other examples of the long life of preserved timber could be given.

Insect Attack

Certain insects attack timber in service, and in tropical countries the termite, or white ant, as it is commonly known, is a serious pest. There are a large number of different species but they can be classified into two distinct groups, namely, Subterranean and Dry Wood Termites. The former build their nests in the ground and throughout their existence maintain contact with these by means of earth-covered tunnels; mechanical methods are commonly employed to protect timber in buildings from their depredations. Buildings in the tropics are frequently built on concrete bases, on piles, or on brick or concrete pillars clear of the ground, and metal shields are used in addition to prevent the termites from gaining access to the interior of the buildings.

The Dry Wood termite differs from the Subterranean type in that the insect colony is formed in the timber into which the flying insects have bored or entered through a crack. These termites are not so widespread as the Subterranean variety but in such countries as the West Indies, where they are active, they cause considerable damage to untreated timber structures, often devouring the inside of the timber, leaving only a thin shell of sound wood. The only effective way of preventing this form of attack is by treating the wood with a substance poisonous to them. Fortunately most of the wood preservatives that are effective against fungi are also effective against both forms of termite.

Termites are essentially insects of warm climates and are not found in Great Britain. In this country the main insect pests of timber are three wood-boring beetles: the death-watch, common furniture, and *Lyctus* beetles. The damage to the timber is caused by the larvae of these insects, for the adult beetles leave the timber soon after pupating, when they fly away and, by laying eggs in fresh timber, can spread the infestation.

The death-watch beetle (*Xestobium rufovillosum*) usually attacks old oak such as old roof timbers; softwoods, though not immune, are rarely attacked.

The common furniture beetle (*Anobium punctatum*) is a smaller insect and attacks well-seasoned timber. Old furniture is often attacked by this insect, which is responsible for the "worm" in antique furniture.

The *Lyctus* beetle attacks only the freshly seasoned sapwood of certain hardwoods, such as oak, ash, walnut, and elm, which have large pores into which the adult beetle can deposit its eggs, This insect often causes considerable damage in timber yards.

Recently, attack of softwood roofing timbers by the house longhorn beetle (*Hylotrupes bajulus*), which is a serious pest in Northern Europe, has been reported in parts of Southern England, but fortunately the attack so far seems to be localized.

Most of the common wood-preservatives used against fungal decay are also effective against wood-boring insects, but the main problem is of satisfactorily treating timber in situ that has been attacked, owing to the difficulty of obtaining sufficiently deep penetration of the liquid to kill the larvae inside the wood. Where their use is not objectionable, coal-tar creosote and similar coal-tar preparations can be used, and many of the solvent and water-borne preservatives are also effective. Timber attacked by death-watch or furniture beetle is best treated during March–September and the treatment repeated each year until activity appears to stop. Ortho-dichlorobenzene and chlorinated naphthalenes are effective insecticides and form the basis of some colourless proprietary products for the treatment of infested timber. Fumigation by expert operators using hydrocyanic acid or methyl bromide has also been successfully employed in bad cases of infestation. Movable furniture can be sterilized by steam treatment in a kiln.

Marine Borers

Marine borers attack timber only in salt or brackish waters, so that it is sometimes possible—for example, in the case of boats—to kill the animals by moving the timber to fresh water for a sufficient period. Marine borers are found in all parts of the world but around the shores of Britain those responsible for most damage are the *Teredo* and the "gribble."

The *Teredo*, or shipworm, is a mollusc that bores deeply into the timber in which it spends its whole life, and it can cause holes up to 2 or 3 feet long and up to 1 inch in diameter. The inside of the timber becomes honeycombed whilst appearing quite sound on the outside.

The *Limnoria* (with *Chelura*) or gribble, which is a crustacean, on the other hand, bores small holes in the surface of the timber to a depth of $\frac{1}{8}$ or $\frac{1}{4}$ inch, but the holes are so numerous that the remaining timber is soon eroded by the sea to expose fresh surfaces for attack. No timber is immune from marine-borer activity, but several, such as teak, turpentine, greenheart,

angelique, manbarklak, ekki, and okan, are highly resistant and as a result have become valuable timbers for marine work. Experience over many years has shown that timber deeply impregnated with coal-tar creosote is highly resistant to this form of attack and is widely used for structures in sea-water. Other preservatives containing copper salts have also given promising results.

Other Forms of Attack

As previously stated, biological attack of timber causes most of the damage in practice, but there are also other forms of attack. Fire is the most important of the physical causes of destruction but it is not often realized, however, that although timber in small dimensions burns readily and constitutes a fire hazard, in large sizes it is more resistant than steel or metals because only the outer layers are burned and it thus retains a high proportion of its strength when involved in a big fire.

Timber can also be damaged by mechanical wear such as abrasion. Generally speaking, wood is fairly resistant to chemical attack, although it is attacked by strong acids and alkalis and some other chemicals. In this respect, too, it compares very favourably with the common metals used for construction. Species differ greatly in their resistance to all these forms of attack, so that certain timbers have found special application for such purposes as flooring and fenders, where resistance to abrasion is important, and for the construction of chemical vats, etc.

Methods of Protection

Having referred to the various agencies that can bring about the destruction of wood in service, it is now appropriate to turn to the methods used for protecting wood from them. It is convenient to consider, first of all, the wood preservatives in common use and then, equally important, the methods by which they are applied to timber.

The antiseptics that have come to be used for preserving wood are more generally referred to as wood preservatives and, although the number of chemical substances that have been suggested at various times is legion, those which have been used on a large scale are surprisingly few. They can conveniently be classified into three types, namely, oil, water-soluble, and solvent, each of which has special properties best suited to different conditions. They all possess certain disadvantages and none is ideal, but most of them have properties or advantages which make them suitable for certain purposes.

The most important requirements of a wood preservative are probably the following. It should: (*a*) be toxic to wood-destroying fungi, insects, etc.; (*b*) be permanent; (*c*) be cheap and available in large quantities; (*d*) penetrate wood easily; (*e*) be non-poisonous to human beings and animals; (*f*) not be corrosive to metals nor affect paints or other finishes; and (*g*) not increase the inflammability of wood.

The choice of preservative for any purpose will largely depend upon the extent to which the more important of these properties are satisfied.

Oil-Type Preservatives

Coal-tar creosote is by far the most important of the oil-type preservatives and has been used on a large scale ever since it was introduced by John Bethell, in 1838, for the preservation of structural and other timbers used under the most severe conditions of exposure. When available, it is the standard preservative for railway sleepers, transmission poles, and marine timbers.

The methods of obtaining creosote from coal tar are outside the scope of this Paper, but it can be said that the wide range of oils produced under the description of creosote oil have all proved to be very effective wood preservatives. In all creosote-producing countries it is prepared to specifications drawn up, in most cases, by representatives of producers and users. It has not yet been possible to establish the relative efficiencies of different kinds of creosote, so that these specifications in the main have been drawn up to include all those high-boiling-point coal-tar oils that are generally available, after experience has shown them to be satisfactory wood preservatives.

The main advantages of creosote oil are that it is (*a*) highly toxic to wood-destroying fungi, insects, and marine borers; (*b*) it is relatively permanent on account of its low solubility in water and its high boiling-point; and (*c*) it is available in bulk and reasonably cheap. Further, it is easily applied to timber and does not corrode metals, so that steel pressure-plants have a long life. Metal fittings, screws, nails, etc., are likewise not affected. Another advantage is that the depth to which the wood is penetrated is readily seen on a boring or on a freshly cut cross-section.

On the other hand, creosote oil has some disadvantages which makes its use undesirable under certain circumstances. It has a characteristic odour which some regard as objectionable and it is unsuited for preserving timber to be used in close proximity to foodstuffs—for example, in refrigerator construction. Creosote also creeps readily from treated wood and will stain adjacent concrete or plaster. Pressure-creosoted wood cannot be painted.

Other materials of the oil type used for wood preservation include coal tar, wood tar and its distillates, and petroleum oils. Though the parent of creosote, coal tar is not so toxic to wood-destroying organisms and, being much more viscous, it does not penetrate wood very well. It is therefore not so effective as coal-tar creosote.

The higher-boiling-point distillates of wood tar are toxic to fungi, etc., but they contain a high proportion of phenolic compounds and are more corrosive to metals than coal-tar creosote. They are effective wood preservatives, but since they are not produced in any quantity or to a standard quality, they are not used to any extent. Petroleum oils are not toxic to

wood-destroying organisms but are widely used as solvents or carriers for toxic materials such as copper naphthenate or pentachlorophenol, and as a diluent for creosote. These solutions are effective wood preservatives and are being used on an increasing scale for much the same purposes as coal-tar creosote.

Water-Soluble Preservatives

Water-soluble preservatives, since they can be handled in a solid or concentrated form, are cheaper and easier to transport than oil-type preservatives, and this is of especial value in countries which have to import all preservative materials or where transport is difficult or expensive. These preservatives do not as a rule involve any fire risk and they are generally odourless. Treatment of wood with aqueous solutions causes it to swell, and it is usually necessary to re-dry the timber before use. After drying, the treated wood can usually be painted or varnished if so desired, so that these preservatives find useful and wide application in the building industry and for the preservation of horticultural timbers.

These water-borne preservatives are leached out from treated wood more readily than oil-type preservatives, and are therefore not so suited for preserving timber used in contact with the ground or in other situations favourable to leaching. Originally, single salts such as zinc chloride and copper sulphate were employed, but in recent years it has become the custom to use mixtures of salts which, though soluble in water, tend to deposit relatively insoluble compounds in the wood after it has been impregnated and re-dried.

Solvent-Type Preservatives

As the name suggests, solvent-type preservatives consist of a toxic material dissolved in a solvent which, after the wood is impregnated, evaporates and leaves the toxic chemicals in the wood. Solvent naphtha and white spirits are commonly employed as solvents, and these penetrate dry wood a little better than the other kinds of preservatives, so that solvent-type preservatives are more suitable where it is only possible to use a surface treatment, such as by brush or spray. The relatively high cost of these preservatives usually restricts their use to this form of treatment, and thus the protection afforded to the timber is usually limited by the small penetration resulting from a surface treatment. Nevertheless, they find very useful applications where their special properties make them particularly suitable. The solvents usually employed do not cause any swelling of the wood, so that these preservatives can be used to treat finished wooden components prior to assembly. It is usually possible to paint or varnish the treated wood satisfactorily after the solvent has evaporated, so that these preservatives are frequently employed for the preservation of motor-car body, cabinet, and joinery work. Many toxic chemicals have been incorporated in these preservatives, but the cost and availability

of the raw materials have tended to restrict them to a few well-tried compounds. Today, the most widely used preservatives of this type contain either metallic naphthenates or pentachlorophenol as the essential constituent. Chlorinated naphthalenes have been employed to a lesser extent, particularly for preserving timber against wood-boring insects, but the toxicity of these compounds to human beings has probably restricted their use.

Methods of Application of Preservatives

If timber is to be preserved against decay and other organisms, it is necessary for it to be impregnated with an antiseptic as deeply and uniformly as possible. Unless this is realized and put into practice, disappointments and failures will be experienced even when the most efficient wood preservatives are used. In the course of about 20–25 years' work at the Forest Products Research Laboratory, a considerable number of causes of premature decay of preserved timber have been investigated, and invariably the failure has been found to be entirely the result of inadequate treatment in the first place. This question of proper preservative treatment cannot be over-emphasized, and if engineers would insist on demanding that timber is properly treated they would be making a valuable contribution to the betterment of the preservation and timber-using industries in Great Britain. In this connexion, a great deal can be learned from American practice, for rapid progress in this field has been made in the United States during the past 30 to 40 years.

In the case of preservation of timber for use in sea-water, proper treatment is essential if it is to be successful. Round piles contain a band of sapwood which readily absorbs preservative liquids, and with Scots pine or Baltic redwood an outer band of creosoted wood of up to 3 inches in depth is readily obtained, which will protect the pile for a very long time. In squaring timber, most of this permeable sapwood is cut away and the exposed heartwood is much more resistant to impregnation, and in practice this rarely receives an adequate creosote treatment.

Surface Treatment and Steeping

Surface treatments, diffusion methods, steeping, the open-tank process, and pressure methods are all employed for applying wood preservatives, and their effectiveness increases roughly in that order. Surface treatments such as brushing, spraying, or dipping, except in the case of sapwood or very absorbent timbers, only result in skin-deep penetration, so that they only afford very limited protection to the wood. Such methods, however, are useful for protecting timber that is to be temporarily used under damp or other conditions favourable to decay, and they are the only ones that can be employed for timber in situ. When applying a wood preservative by

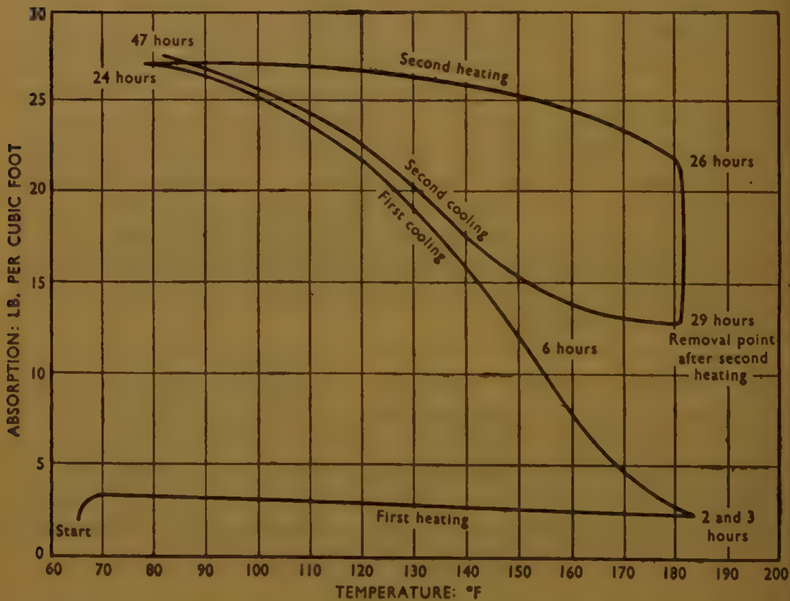
brush or spray, it should be applied liberally and the timber allowed to absorb as much of the liquid as possible, especially at joints and into end grain where decay usually starts. Oil-type preservatives are best applied hot.

Steeping, which means that the timber is completely submerged in the liquid for a period, is more effective than the foregoing, especially if all cutting and boring of the timber are first carried out.

Open-Tank Process (see Fig. 7)

The open-tank hot-and-cold process for impregnating timber is a simple though effective method of preservation, and requires only the minimum of

Fig. 7



Curve showing Absorption of Creosote by 4-inch-by-2-inch Scots Pine Sapwood, during the Open-Tank Process, and the Effect of a Second Heating Period.

equipment. It is without doubt the best alternative method of treatment when pressure-treating plant is not available. With permeable timbers, results comparable with pressure treatment are obtained. The treatment is carried out in an iron or steel tank in which the preservative liquid can be heated either by an open fire, steam, or other means. The timber is first put into the tank and then covered with the preservative, and it is kept submerged throughout the treatment. The liquid is then heated to about 180 degrees F., and this temperature maintained for 1 or 2 hours, after

which the heating is turned off and the contents of the tank allowed to cool. During the cooling period the air which was expelled from the wood during the heating is replaced by liquid, and as the volume of air displaced is a function of the maximum temperature reached during the heating period, the absorption of preservative liquid is governed by the difference between the temperature of the liquid when hot and that when the wood is removed from the tank. Permeable timbers such as alder, beech, birch, hornbeam, lime, oak sapwood, sycamore, Scots and Corsican pines, and silver fir can be almost completely impregnated in the sizes commonly used. The heavy absorptions obtained in this way considerably increase the weight of the timber, and the benefit of deep impregnation with a reduced retention of preservative can be obtained by re-heating the preservative after it has cooled before the timber is removed. This has the effect of expelling some of the liquid absorbed by the wood.

Diffusion Treatment

Other methods for preserving timber include those which rely on the diffusion of water-soluble salts into the timber, but these are not extensively used in Britain. One such method consists of injecting a preservative paste into the timber by means of a hollow needle. The injections are made at intervals over the surface of the wood, and if the wood becomes sufficiently moist the preservative diffuses from the incisions into the surrounding wood.

Pressure Treatment (*see Fig. 8*)

Pressure treatment of timber is by far the most efficient method and the most widely practised. Pressure plants operated by firms specializing in this work are distributed in various parts of Britain, but are mainly located at the important timber-importing ports. These plants are used to preserve railway sleepers, marine timbers, paving blocks, fencing material, etc., usually to an appropriate specification. British Railways also have pressure plants for the treatment of sleepers and other timbers used in railway work. Some estates operate their own pressure plants to treat fencing and other estate timbers, whilst others are content with open-tank equipment.

The principal methods of pressure impregnation of timber are the Full Cell and Empty Cell processes, and these are both sometimes employed in conjunction with the Boulton, or boiling under vacuum, conditioning process.

The Full Cell or, as it is sometimes called (after its originator), the Bethell process has been in continuous use since 1838 and is used in Britain for the creosoting of railway sleepers and marine timbers. It is also the normal method employed with water-borne preservatives. Briefly, it consists in first subjecting the timber contained in a pressure cylinder to a vacuum of up to about 28 inches of mercury for $\frac{1}{2}$–1 hour ; then filling the

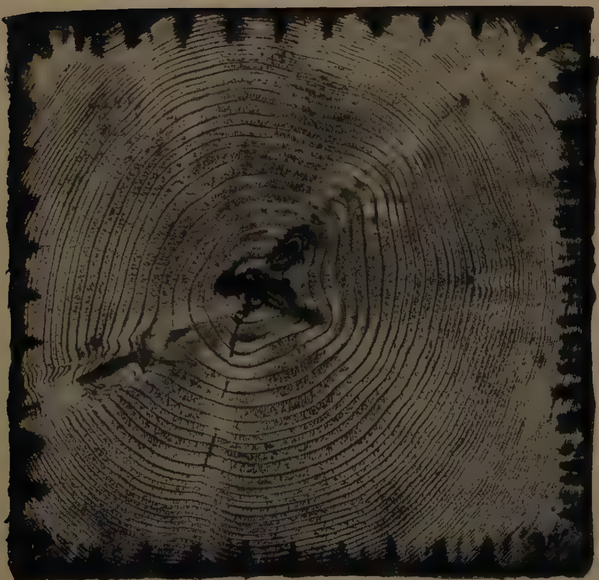
cylinder with preservative and applying pressures of up to 180–200 lb. per square inch until the required amount of preservative has been injected into the timber. The cylinder is then emptied of preservative and the treated timber is held for a short period under a vacuum—in the case of creosoting this cleans up the surface of the timber. It is usual and beneficial to heat the preservative throughout the treatment, and when creosote is used this is heated to 180 degrees–210 degrees F. Apart from the temperature of the preservative liquid, the time for which pressure is applied is the most important factor affecting the amount of preservative injected and the depth to which it penetrates. In the early stages of the pressure period the timber absorbs the liquid at a fairly uniform rate, but this gradually slows down to a very low rate, often too low to be readily observed. When this point is reached the timber is said to be treated to refusal. The rates of absorption vary considerably with different species, and whereas permeable timbers such as Corsican pine or beech are completely penetrated within a few minutes, others, such as Douglas fir, larch, or oak heartwood are not completely penetrated even when the pressure is maintained for several days. As stated earlier, preservatives penetrate wood very much better when they are hot, and when creosoting refractory timbers such as Douglas fir it has been found desirable to employ oil temperatures as high as 210 degrees F. When these high temperatures are used, however, it is necessary to avoid using high oil-pressures since otherwise the timber is damaged by what is termed "collapse."

The Empty Cell processes differ from the Full Cell method in that the wood is not subjected to a preliminary vacuum period. In the Rueping process, which was introduced in about 1902, the wood is first subjected to compressed air. The cylinder is then filled with preservative while maintaining the air-pressure at a constant value, and hydraulic pressure is then applied to force the preservative into the timber until the required absorption is obtained. The pressure is then released and the air that has been compressed into the inner parts of the wood is allowed to escape; in doing so it expels the excess preservative, leaving the cell walls coated with preservative. A final vacuum is used to assist in allowing the air to escape. This process results in deep impregnation of the preservative with a moderate retention, and is usually confined to creosoting. It has been the standard method for creosoting transmission poles in Britain since about 1913, and is also the standard method for railway sleepers in the United States and Canada. The Rueping process is also used for the treatment of wood paving blocks, fencing, and building and other timbers, where as clean a treatment as possible is desired.

Another Empty Cell process, known as the Lowry process, is one in which neither vacuum nor air pressure is applied initially to the timber. The cylinder containing the timber to be treated is filled with preservative and pressure is applied until the required absorption results. The compression of the air originally in the wood serves to recover a small

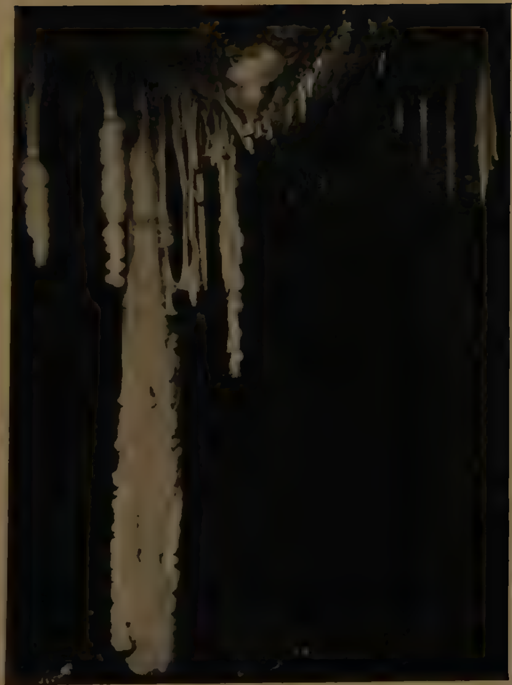
Fig. 1(a)

Fig. 1(b)



MARINE PILING SHOWING ADVANTAGE OF USING ROUND AS AGAINST SQUARED MATERIAL (*a*) BALTIC REDWOOD; (*b*) INCISED DOUGLAS FIR. (Note deep band of creosoted wood in (*a*).)

Fig. 2



MINE TIMBER SHOWING FUNGAL GROWTH RESPONSIBLE FOR DECAY OF UNTREATED TIMBER

Fig. 3

INCISING MACHINE

Figs 4

Sections of Douglas Fir Sleepers showing Effect of Incising on Penetration of Creosote (Sleepers 1 and 2 Incised).

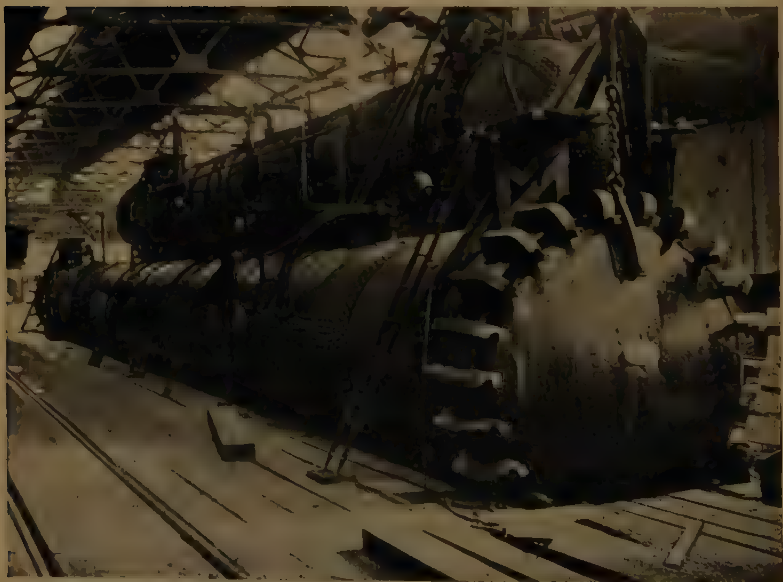
Figs 5

Experimental Railway Sleepers showing Reduction of Deep Splitting as a

Fig. 6

Railway Sleepers Stacked prior to Creosoting

Fig. 8



Pressure Plant used for Creosoting Railway Sleepers

TABLE 1.—APPROPRIATE PRESERVATIVES FOR DIFFERENT USES OF TIMBER

Class of timber or structure	Type of wood preservative		
	Oil (e.g. coal-tar creosote)	Water-soluble	Solvent
Railway sleepers, transmission poles, marine timbers, fence posts, wood-block paving, hop poles, bridge timbers, coal barges.	The most suitable and satisfactory. Best results by pressure impregnation but open-tank satisfactory with permeable timbers. Impregnation treatment essential for long life.	Not very suitable, not being sufficiently permanent under severe conditions of exposure. Pressure treatment with those resistant to leaching suitable for the less severe conditions but not in contact with the ground.	Would be suitable but high cost generally rules these out for an impregnation treatment which is essential for for long life.
Wooden farm buildings, garages, fencing above ground, pig sties, chicken houses, weather-boarding.	Generally suitable, preferably applied by pressure. Brush treatment if carried out periodically adds to the life. (Not advisable to admit livestock to freshly creosoted structures.)	Suitable if timber is impregnated under pressure. Treated timber can be painted if so desired.	Suitable. Treated timber can be painted.
Factory roofing, building (housing) timbers, ship and boat timbers, motor car and lorry bodies, mining timbers.	Not as a rule suitable but can be used if there is no objection to odour and where painting is not required.	Suitable. Preferably applied by pressure.	Suitable.
Horticultural timbers, i.e. seed boxes, bulb boxes, glass-houses, etc.	Not suitable if timber is in close proximity to plant life or where painting is required.	Suitable. Preferably applied by pressure.	Suitable.
Refrigerator timbers.	Not suitable.	Those resistant to leaching or non-poisonous are suitable.	Suitable when odourless.

amount of the liquid injected into the wood when the pressure is released, and a long final period in a vacuum is used to assist in this.

The Boulton process takes its name from a former distinguished member of the Institution of Civil Engineers, Sir Samuel Bagster Boulton, who patented it in 1879.* This is a combined seasoning and creosoting treatment for green timber and, although not used very often in Britain, is the usual method for creosoting Douglas fir and western hemlock on the west coast of the United States and Canada. The timber is immersed in hot creosote contained in the treating cylinder and subjected to a vacuum, the effect of which is to lower the boiling point of the water in the wood, which boils off without seriously damaging the wood. After a period of about 12–24 hours, or when water is being driven off from the wood only at a very low rate, the timber is given a normal creosote treatment by the Empty or Full Cell method.

Before timber is impregnated with a wood preservative it should be seasoned until all free water in the cells has been removed, and this represents a moisture content of the timber of about 25–30 per cent, there being a slight variation with different species. There are two good reasons for doing this: first, it is not possible to inject another liquid into wood containing much water and, secondly, any splitting during subsequent drying of the timber would almost certainly expose untreated wood. Poles should therefore be barked, taking care to remove all inner bark in this operation, and then stacked for air seasoning. Sleepers likewise should be suitably piled for seasoning prior to creosoting. All cutting, machining, and boring of the timber should, so far as possible, be done prior to treatment, since these also, if carried out after treatment, will expose untreated wood. Where these operations cannot be done until after treatment, all exposed untreated timber should be given a liberal application of preservative, and holes preferably treated with a pressure bolt-hole treater. When the tops of driven piles are cut, an application of hot tar or bitumen can be applied with advantages after the untreated wood has been given a good coat of preservative.

From what has been said, it will be seen that for the effective preservation of wood the method of applying the preservative is as important as the actual preservative used. It can be said that, in general, an impregnation treatment by pressure will give the best results, though the open-tank hot-and-cold process will also give satisfactory results with permeable timbers. Surface treatments such as dipping, brushing, or spraying afford the minimum protection and usually only give protection for a limited period unless repeated at frequent intervals.

Table 1 illustrates appropriate uses of the various types of wood

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* British Patent No. 1954, 15th May, 1879. It is described in S. B. Boulton "On the Antiseptic Treatment of Timber." Min. Proc. Instn Civ. Engrs, vol. 78 (1883–84, Pt IV), p. 97.

preservation of some common structures. At the present time, the only commercial pressure treatments available in Britain are with coal-tar creosote and two water-borne preservatives, "Celcure" and "Tanalith." In addition, there are facilities for the pressure impregnation of timber and plywood to render them more fire-resistant.

Conclusion

In bringing this Paper to a conclusion the Author would like to ask engineers in general to take a more active interest than they have in the past in the durability of any wood they use, and to request them to insist upon a high standard of preservative treatment from the treating firms. By so doing they will help to improve the standard of preservative treatment in Britain, which is much lower than it should be in the country where wood preservation, as the term is understood today, had its origin in the early 19th century.

Acknowledgements

The Author is indebted to the Director of the Forest Products Research Laboratory for permission to present this Paper.

This Paper is accompanied by eight photographs and one diagram, from which the half-tone page plates and the figure in the text have been prepared.

Discussion

The President, in proposing a vote of thanks to the Author, said that just over 100 years ago, on 11th January, 1853, the first Paper on timber preservation had been read before the Institution, by Mr H. P. Burt, Associate. That Paper was entitled "On the Nature and Properties of Timber, with descriptive particulars of several methods, now in use, for its Preservation from Decay."[1] Reference was made in the Paper in question to John Bethell's method, introduced in 1838, and with the Paper was a fine lithograph showing the plant for applying that process at the author's works in Rotherhithe.

The present Paper was not controversial, although at the beginning the Author had made some remarks which the President hoped would bring engineers to their feet, such as that many engineers did not give sufficient, if any, attention to durability, and to the relative merits of squared and round piles.

Mr Jack Duvivier observed that he had been concerned nearly all

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[1] Min. Proc. Instn Civ. Engrs, vol. XII (1852–53), p. 206.

his working life with maritime works, and was particularly interested in the subject of timber preservation.

After the 1914–18 war, engineers had been able to obtain pitch pine, and that had been extensively used in maritime construction. After a time, pitch pine had become practically unobtainable, and Douglas fir had been used instead. Jarrah had been imported from Australia in large quantities between 1918 and 1939 and was an excellent timber. After 1939, no more jarrah had been imported into Great Britain, and for a time it had been extremely difficult to obtain Douglas fir, owing to the dollar situation. Furthermore, it had been necessary to abandon incising during the war, largely because of internal transport difficulties, and, as the Author had shown, satisfactory impregnation was not obtained in those conditions. It had been necessary for a time to use unseasoned home-grown elm in the absence of any cheap alternative, and that had not been altogether satisfactory. A number of imported hardwoods, such as ekki, had recently been made available, but Mr Duvivier had been told that no more ekki was to be brought into Britain, but that there would now be ample supplies of greenheart.

The maritime engineer had to use the timber that was available on the market at the time and that necessarily complicated the question of preservation. The present price of incised and creosoted Douglas fir was not much less than the price of imported hardwoods such as ekki, greenheart, or brushbox, and since the latter were very much stronger in addition to being much more durable, the tendency was to use more untreated hardwood and less treated softwood.

Mr Duvivier then showed a number of slides of aerial photographs of various places on the coast of Great Britain where timber had been extensively used, and described the method of preservation that had been adopted and the reasons in certain cases for omitting the usual preliminary treatment of the timbers.

One slide showed a timber lifeboat slipway at Sheringham, where there had been a considerable amount of trouble and difficulty, owing to abrasion. The beach was composed of large grey flints which were rolled to and fro by the storm waves and which had a tremendous grinding action both on concrete and on timber. The slipway had been built in 1936 of incised and creosoted Douglas fir and partly protected by steel plates which had been placed for the purpose of protecting the timber against damage by the tracks of the lifeboat carriage. After a few years, however, 3-inch planks had been worn away, in places, to less than ½ inch in thickness. In 1948, the lower lengths had been rebuilt in elm, the only timber which could be satisfactorily obtained at that time. Those had lasted 4 to 5 years, and recently it had been necessary to renew them. The replacements consisted of 9-inch-by-3-inch planks of greenheart, but even those were beginning to show signs of wear after a few months' exposure.

A later slide showed the Suffolk coast at Aldeburgh. A scheme had

been carried out shortly after the 1939–45 war for the protection of that old town. It comprised the construction of a number of groynes which had been built of elm planking and elm sheet-piles. Two or three years after the job had been finished it had been found that the *Teredo* had been active. The remedy adopted had been to drill two ¾-inch-diameter holes vertically downwards in each sheet pile to a depth of 2 feet to 2 feet 6 inches, and those holes had been filled with copper sulphate and plugged with a cork. The copper sulphate had soon begun to leach out, as shown by the discoloration of the sheet piles. It was too early yet to be definite about the results of the treatment, but it would appear that it had been successful, judging by what had been seen so far. Incised and creosoted Douglas fir main piles and walings used in some groynes had not been attacked.

A few years previously, *Teredo* had become a real menace in the impounded section of the west arm of Shoreham harbour, and the theory was that the cooling water which was discharged from the Brighton power station had raised the temperature of the water to a degree which was convenient and comfortable for the *Teredo* to thrive in, and that it had actually been brought into the channel in the timber of a boat which had been brought in for repair.

At Weston-super-Mare, a slipway had been built for the Lifeboat Institution in 1903, comprising jarrah piles and bracings and a steel decking. The entire structure had been coated with tar every year under a regular maintenance programme. When Mr Duvivier had inspected the slipway 2 years previously, he had found most of the piles in perfect condition, but the ends of the bracing members had been severely attacked by *Limnoria*. It had been necessary recently to rebuild the steel superstructure, and the opportunity had been taken to encase the timber piles in gunite, with a view to reducing the cost of maintenance. A similar repair to a jarrah slipway at Tenby in Pembrokeshire which had been carried out a few years previously had given very satisfactory results.

Mr K. L. May said that if the Paper had been written, accepted, and properly acted upon 25 to 30 years ago the electricity supply industry of Great Britain would now be saving thousands of pounds every year, and would continue to do so for the next 20 years or so.

With reference to the Author's accusation that engineers gave insufficient attention to the question of durability, Mr May thought it fair to mention the failure of timber suppliers to work properly to specifications such as B.S. 139, which covered telegraph and transmission-line poles. The engineer was not necessarily an expert in timber; he had to place reliance on the timber-supplying firms, and to some extent Mr May felt, from factual experience in the field, that occasionally those firms had failed in their duty during the past 25 years.

He agreed with the Author's statement on p. 650 that "a longer life

could be obtained from many of the railway sleepers and electricity transmission poles." It was interesting to note that no reference was made there to telegraph poles, and quite properly so, because the Post Office had for many years past employed resident pole inspectors, and had had a very handsome return for that initiative and expense. Many poles were failing after 15 to 20 years which, if properly treated and supplied in accordance with British Standard specifications, should have lasted 40 to 60 years.

He referred to a line of telegraph poles between Newbury and Reading which he had been responsible for buying from the Post Office, for use on his employers' electricity network during the severe timber shortage in 1945. The poles, 250 of which had been bought, ranged from 60 feet to 30 feet in length. Most of them had been installed in 1898, and when taken out in 1945, every one had been in perfect condition. They had originally been treated by the Full Cell process. Every one of those poles had been in such good condition that it had almost seemed proper to re-erect them as they were on the network of the electricity supply company, but the precaution had been taken of having them sent to depot and re-treated by the Rueping process. He confidently expected at least another 50 years of life from them, which meant that from the time when they had been brought raw to Britain from Scandinavia they would have had at least 100 years of life. He had attended a recent conference in Germany, and when he had mentioned that case there had been exclamations of surprise that anyone should think in terms of 100 years of life for timber if it were treated twice.

At that conference, the German industry had called together 200 of its representative members for a meeting to deal solely with timber preservation. He mentioned that to show the value which a foreign country—one which had much greater timber resources than Britain—attached to the preservation of timber. The Germans were not in quite so fortunate a position as were the British, in that they could not afford to buy Scandinavian red fir. Their natural product was spruce, which was not so suitable for proper treatment by creosote. The result was that the Germans were treating their transmission-line poles by water-soluble salts, sodium fluorides, mercuric chlorides, and so on. It had been interesting to find that 15 to 20 years was regarded as the usual maximum life of their transmission-line poles. One result of the conference had been a suggestion to the effect that it was necessary to re-treat those poles at ground level by wrapping bandages on them in rotation every 8 years, since the water-soluble salts leached away and lost their toxicity after a period of about 8 years.

Mr May then displayed a slide showing examples of good and bad impregnation with creosote. In one example, a section showed the effect obtained if one side of the wood was unseasoned or absorbed moisture (for example, through exposure to rain); when creosoting, the water had been

driven up against the heartwood and the creosote had piled up against it, thus leaving a band of unprotected sapwood.

It was popularly assumed that timber would first rot at ground level, but if it had not been properly treated the rot did not always start there. Mr May's second slide showed a pole which was almost sound at ground level, with attack starting 6 feet above, and there were large cavities higher up to within 9 feet from the top of the pole.

A third slide showed a standing transmission-line pole having an outer band, about 1 inch thick, of creosoted sapwood in good condition. There was, however, a complete circumferential inner cavity caused by the rotting away of untreated sapwood, thus leaving a detached centre core, or column, of heartwood.

Mr J. P. M. Pannell, who said that his remarks would refer mainly to maritime works, observed that the Author had referred to the advantage of round timber piling. The advantage of a rectangular section from the constructional point of view was a strong factor in the choice of using round or square timbers for piling. Perhaps the engineer might help to get over the difficulty to some extent by devising a constructional detail similar to the timber connectors, used increasingly in construction, which would be designed to make a good connexion between a round vertical member and horizontal cross-members and braces. Another factor to be considered was the effect of bolt-holes, which weakened the protection afforded by wood preservation.

On p. 650, the Author had referred to the decreasing quantities of naturally resistant timbers. Mr Pannell had no doubt whatever that engineers who were responsible for maritime works would prefer timbers which had a natural resistance to those which had to be given such resistance by man after the timber had been felled. The Author had been a little pessimistic, perhaps, in referring to the decreasing quantities available, particularly in the case of greenheart. The shortage of greenheart was probably largely a matter of transport, and delay in the opening-up of the vast quantities available in British Guiana. If the engineer insisted on having greater quantities of greenheart, the material might be made available to the great advantage of all concerned.

Mr Pannell wished to add pyinkado to the list of resistant timbers given on pp. 653–4. He did not think that it was still available in very great quantities, but there was still some in the timber yards in Great Britain, and experience had shown that it was very resistant to the attack of the gribble.

On p. 656, reference was made to water-soluble preservatives, and the Author seemed to imply some doubt as to their effectiveness in maritime conditions. With regard to Mr Duvivier's remarks about what had happened at Shoreham, it might be of interest to mention that samples had been placed on test at Marchwood, near Southampton, in anticipation of the establishment of a power station, and the frames of specimens had

included several kinds of samples. At Mr Pannell's invitation, the processing firms interested in the water-soluble processes had promised to let him have some samples to put out, but those samples had not arrived, and he had a grave suspicion that their absence might be associated with doubts as to whether they would survive.

On p. 657, the Author had referred to the difference between heartwood and sapwood. In that connexion, Mr Pannell quoted a passage of particular interest in view of what the President had said about Mr Burt's Paper. In the Minutes of the Southampton Harbour Board, dated 22 September, 1853, a report by Mr John Doswell Doswell, the Surveyor to the Board (an assistant at one time to John Rennie), stated that :—

> "In order to ascertain the quantity of Creosote forced into the American Elm Piles, I carefully weighed a dry pile before it was put into the solution and again after it was taken out.
>
> "Cubic contents of the pile 28 feet 2 inches, increase of weight 224 lb., which I find gives 40 gallons per load, 35 gallons being an usual requirement for close-grained timber—I also had the same piece of timber weighed by the Customs large scales and it differed but one pound from the Weighbridge."

On the 13th October, 1853, Doswell reported that the progress of creosoting was satisfactory as a whole, but its effect had varied between 31 and 40 gallons per load, and he recommended testing one piece of timber per load. Mr Pannell thought that that referred to timber creosoted by Mr Burt's firm.

Three or four years ago, Mr Pannell's Board had had occasion to draw some piles from that very construction, and he had brought with him a piece of the American elm timber referred to in Doswell's report. That was relevant to some of the other remarks which had been made, because there was penetration of creosote into the American elm in the sapwood, but almost none where the sapwood had been sawn away and only heartwood left.

That raised another very important factor which the Author had dealt with on p. 659—that of specification. For 100 years or more, the specification for creosoting seemed to have been based on the quantity of creosote absorbed into a given amount of timber. There did not seem to be any relationship in the ordinary creosoting specification to the actual penetration. It was known that with incising a fairly consistent cover to the vulnerable timber was obtained, but it seemed to Mr Pannell that it would be necessary for engineers to establish a sound specification which bore a genuine relationship to the quantity of creosote which was protecting the timber, as against the creosote which could be written off as waste.

He had also brought with him a piece of greenheart which, for 60 years, had been used as piling in waters very heavily infested with gribble, and the heartwood was perfectly sound. Even with a naturally resistant

timber the sapwood deteriorated and left the heartwood. The line of attack had almost followed the annual rings.

Mr R. G. Bennett observed that many people regarded wood as a material for temporary construction only, and therefore not worth taking pains to preserve. No one apologized for the fact that iron and steel were painted, covered with tar, or treated with Angus Smith's solution or sherardized, and the reasons which prompted an engineer to treat metal in that way should lead the user of wood to employ some kind of preservative. It was not merely a matter of making an non-durable substance durable; it enabled that part of the wood which was so often thrown away, the sapwood, to give the same durability and strength as the heartwood which was so much prized by the man responsible for a structure.

He thought that the success achieved in the preservation of Post Office telegraph poles was explained by the attention which the Post Office paid to technical literature on the subject, and to the employment of its own inspectors at all stages. That was not because they did not trust the trading firms; firms of repute existed in Great Britain, with both oil-type and water-soluble preservative plants. It was a question of taking the responsibility for the supply of the timber and the application of the preservative process.

A firm which relied on a chance supply of wood for some unforeseen requirements was asking for trouble. The Post Office, possibly because they had the deep purse of the Treasury to draw upon, anticipated their requirements 2 or 3 years in advance.

Referring to the veteran poles which had lasted for 70 years, he pointed out that the economic life of a pole under present circumstances was about 27 years, so that a veteran pole could in fact be an embarrassment; it meant that the job had been done too well.

That was why, in 1913, the G.P.O. had changed over to the Rueping system, which up to the present had given a life approximately equal to the economic life. Another advantage of the Rueping process was that the interior cell walls of the wood were lined with preservative but the bulk of the preservative, which previously had merely filled up a cavity, had been withdrawn, so that a lighter, cheaper, and cleaner pole was obtained, but, so far as could be ascertained at the moment, a very well preserved pole, or at any rate one good enough for the economic service which was expected of it.

It was essential that all the cutting and boring and prefabricating of the structure should be completed before the wood was given its preservative treatment. It was foolish to put a preservative belt round the sapwood of a member and then cut a lot of it away by making a slot or boring holes through it and so expose the untreated wood in the centre.

On the question of a specification, he sympathized with engineers who failed to get the kinds of timber which were recommended and to which they had become accustomed. That position was always liable to arise

during a war, and it was to be hoped that there would be an improvement. There were, however, British Standard specifications for wood preservation, and if the users of preserved timber would only see that the work which was done and the materials which were used were in accordance with the specification, he did not think that they need worry about durability, which was what wood preservation was intended to give.

Mr B. A. Jay observed that the Author had made the point that timber was not necessarily a non-durable material, and had quoted a few of the durable timbers. Subsequent speakers had mentioned others, and Mr Jay could add to that list. He would like to mention one or two woods for marine work: for example, *Basralocus*, or Angelique, had been used recently in Great Britain with success though, since it was a Brazilian timber, there was a tendency for continuity of supply to be a difficult problem. There were also okan, ekki, and opepe from West Africa. Reference had been made to the short supplies of greenheart, which was widely used in marine work. Those supplies were now improving.

Two speakers had referred to Shoreham harbour and to the problems there. The Timber Development Association had for the past 2 years been carrying out some small-scale experiments there, not only with various types of untreated but resistant timber, but also with a number of preservatives. They were obtaining some interesting results. It had been mentioned that the higher temperature of the water might have been the cause of some of the trouble, and that seemed to be true. The other point was that there had been a sudden cessation of attack after about 18 months, and for 6 months there had been almost no continuance of attack. That might be because of the change in content of the water, and not only to the temperature. So far, some of their tests had shown that one of the best timbers untreated was the okan, which was sometimes called African greenheart. Some of the preserved timbers, even those treated with a water-borne preservative, had shown extremely good results.

In Table 1, the Author had indicated that, for marine work and other ground-contact purposes, water-borne preservatives were not very much used. Mr Jay joined issue with the Author there. Possibly the Author was being ultra-cautious, because some results, including those contained in the report of the Sea Action Committee of the Institution, showed that at least one preservative of that class had given very good results for a considerable period in marine work.

Another point which arose from the indication of the properties of wood in general was the permeability of timbers which were not necessarily durable. Here it would seem that a compensatory law applied, and if a wood was not durable it was often easy to treat. Elm was easy to treat, but perhaps beech was the best example; it was one of the easiest timbers to treat, but one of the most vulnerable when not treated.

Reference had been made to the necessity for doing cutting, boring,

and so on before the treatment was applied. Where that was impossible, it was essential that extra treatment should be given after any cutting had been done. It was mentioned on the last page of the Paper that there was now a hand-operated gun available for treating bolt-holes under pressure after they had been bored in situ. That was a very useful way of preventing marine-borer troubles through bolt-holes and so on.

Mr Jay had been interested in the controversy regarding round versus square piles, but he had not yet heard mentioned an interesting Australian development against gribble attack, which took the form of a floating collar on a round pile, which floated up and down with the tide and carried with it a preservative which treated the pile. That affected the pile only between the tide levels, but that was where the gribble did its worst damage. It was not much use against the *Teredo*, which might start at the mud-line or elsewhere.

Those who were too busy to read the voluminous literature on timber and timber preservation could well make use of the bodies which existed for the purpose of giving information about timber. The Author's own organization, the Forest Products Research Laboratory, could be consulted, and it might not have been realized by some engineers that there was a body concerned purely with timber preservation, the British Wood Preserving Association, which existed for the purpose of helping those who were too busy to read all the literature and who wanted to know the answers quickly. There was also Mr Jay's own organization, the Timber Development Association, which was always glad to help. There was therefore not much excuse for ignorance, when one could telephone or write to those who could give the information required.

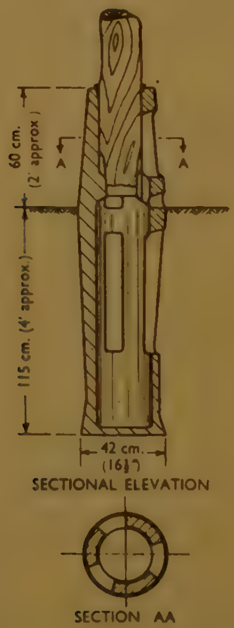
Mr J. B. K. Ley said that in Australia the bulk of the timber was hardwood, and unfortunately it was relatively impermeable to preservatives. That applied both to the sapwood and to the heartwood. He had not been aware of the "round versus square" controversy, because the general practice in Australia was to avoid cutting into the timber, and to preserve the sapwood as much as possible.

It was mentioned in the Paper that sapwood was of great value because it absorbed the preservative and then formed a protective layer. In Australia, it was regarded as a protective layer in itself if it could be left intact. He would be interested to know if the Author thought that that was merely a fallacy so far as the hardwoods were concerned. A great deal of trouble had been taken to design joints to protect the sapwood, and also to protect the joints from the weather when it had been necessary to cut into the sapwood, and that was dealt with very fully in Australian literature.

He had noticed in Italy an interesting form of reinforced-concrete chair for supporting timber telegraph poles (see *Figs 9*). Fungus thrived on moisture and air and therefore the idea was to eliminate the vulnerable part where the pole met the ground and where fungal attack usually

occurred. That was achieved by lifting the pole clear of the ground in such a way that air could circulate and water drain away from it. That method of supporting poles was not only favoured in Italy, but under certain circumstances its use was obligatory by regulation: for instance, where power lines crossed telegraph systems, the electricity supply poles were required to be supported in such chairs. There were a number of variations in the design of the joint, some being entirely in steel, but the object was the same in each case, namely, to avoid the junction of the wood with the ground.

Figs 9



POLE SUPPORT (STANDARD SIZE)

Mr May had referred to a case where decay had begun near the top of a pole. The top was a weak place, and if there were cracks at the end of the grain, rain-water could be trapped and the fungal attack could start there as easily as at the ground line or at a badly designed joint. It was for that reason that the tops of telegraph poles were sometimes covered with galvanized iron.

In Australia, the timber was frequently seasoned in position, and structures had to be designed accordingly. Timber was felled as near as possible to the site of the job, and used almost at once. It had been found necessary to allow for the difference between the drying rates across

the grain and along the grain. A pole dried on the end of the grain much more rapidly than across the grain, and if timber was freshly cut, sap would pour out at the ends and there would be a difference of shrinkage rate between the area close to the end and further away. As a result there would be cracking at the end. Those cracks not only weakened the timber but allowed fungus to get in. That effect was overcome by painting petroleum jelly on the ends, which reduced the rate of drying along the end grain and prevented cracking.

Another problem which arose when dealing with green timber was the difference in shrinkage rates. Australian timber displayed an average shrinkage rate of $\frac{1}{16}$ inch per inch across the grain, whilst along the grain, shrinkage was small; so that in designing a structure it was necessary to provide for that effect.

A good deal had been said about the durability of timber. Australia was very fortunate in its hardwoods; they lasted a relatively long time, sometimes under the most unfavourable conditions. The number of varieties was large and they had a wide range of durability. Some species contained a natural preservative which made them very resistant to the agents of decay. For instance, Turpentine (*Syncarpia laurifolia*) was unpalatable to marine borers; Cyprus pine (*Callistris glauca*) was not favoured by the white ant or termite; and Huon pine (*Dacrydium franklini*) was practically everlasting.

In the past, Australia had tried to get rid of her timber to make way for settlement, but now that practice had to give way to proper forestry methods to assure sustained supplies of a material which in itself was a great national asset. Temporarily there was a serious shortage in the supply of some of the more valuable species.

If properly selected and used in the correct way, timber was not a temporary material but was very durable indeed. For example, if used in foundations beneath the ground-water table and away from air, it was safe from fungus and other agents of decay. Owing to that fortuitous circumstance, archaeologists were able to uncover ancient wooden ships which had been preserved for centuries by a protective mantle of mud.

Mr B. F. Saurin, referring to gribble attack, said that it was generally understood that the greatest danger arose between low water and high water. However, only a week previously, the Superintending Civil Engineer of the Admiralty in the Clyde area had shown him a large number of piles which had been pulled out from rapidly constructed jetties built during the 1939–45 war, and it had been very noticeable that the gribble attack was concentrated immediately above the mud-line. The section of the piles had been very severely reduced at the mud-line, and then the amount of reduction of section progressively became less as the level rose, until the original section was regained a few feet below high water.

That seemed not to be what was generally expected of the gribble. However, he had also had the opportunity to inspect some piles at Blyth

in Northumberland, where apparently the same effect from gribble attack was experienced. Had the Author's observations on the behaviour of the gribble suggested that that was to be regarded as normal or abnormal?

*** **Mr F. P. Dath** observed that the Paper and discussion had made a valuable addition to the store of information available to civil engineers. He felt, however, that there was still wide scope for further research and that the perfect solution for wood preservation was still to be discovered. Modern methods considerably retarded the decay of timber but had not eliminated it. He wondered if there was not the greatest scope for improvement in the methods of application.

He noted that the Author had been careful to state the limitations of the treatments he had described.

Mr Dath noted that Table 1 dealt mainly with the treatment of outdoor timber. What treatment would the Author recommend for internal finished woodwork? The woodwork in the Bodleian Library at Oxford University had been successfully treated with paradichlorobenzene against the ravages of woodworm.

The Author, in reply, said that Mr May was right in defending engineers. He (the Author) admitted that his criticisms had been intended to stimulate some reaction from engineers. Nevertheless, at the back of his mind there were too many instances of extremely costly and valuable structures which had come to his notice in recent years—including, for instance, some very large flour mills—where untreated piles had been put in. In the case of the flour mills, if the engineers or consultants had discussed the matter with anybody with any experience of timber at all, they would have been told that untreated piles should not be used, in view of the circumstances of the made-up ground on which those mills had been erected. Now, 15 years later, the whole of the buildings had to be re-piled. He did not know how much it would cost or how it would be done, and the engineering firm responsible found it a serious problem. He did not complain that they were worrying him, but it was always difficult to convince people, even at that stage, that such a catastrophe could have been avoided. He spoke in that way because those were not isolated instances, but happened in many places; timber had been used unnecessarily badly through lack of foresight—sometimes, perhaps, owing to the war.

That brought him to Mr May's point about the suppliers being sometimes to blame. The Author agreed, but thought that the matter was more likely to be put right if engineers insisted on having the treatments properly done. They were ultimately responsible. The suppliers would play their part only if the demand came from the users, and it was the users in the main who had to be educated to know what they wanted and to

*** This contribution was submitted in writing upon closure of the oral discussion.—Sec. I.C.E.

see that they got it. Probably Mr May would agree that that summed up his own experience; he had had difficulties to contend with in getting poles, but now, by looking after the job himself, he had no need to worry about one supplier more than another, and could make sure that he got what he wanted.

Mr May had referred to the spruce poles used in Germany. There was no experience in Great Britain which would permit comparisons to be made, but the Author could confirm Mr May's statement that the Germans seemed to be content with a life of 15 or 16 years for a transmission pole, which was a short life by British and American standards.

Mr Pannell had mentioned that specifications did not include penetration, but they certainly did so if one used round piling, and it was clear that whatever the absorption specified for the treatment, an overriding consideration in all cases was that there had to be complete penetration of any sapwood. The penetration was linked up with the absorption specified and the size of the timber, so that penetration was indirectly looked after in the square timber.

The Author was glad that Mr Bennett had given the Meeting the benefit of his long and wide experience on the question of preservation.

Mr Jay had mentioned the water-soluble salts. The Author would defend his position there, because there was no evidence yet that water-soluble salts were so suitable for marine work; they had been in use for only 20 years, whereas creosote had been in use for more than 100 years. Some of the water-soluble salts might have some use, but the mere fact that they were water-soluble at once suggested that they would not be so permanent as something which was insoluble in water for the class of work in question. In most countries which practised wood preservation, specifications did not allow water-soluble salts for the treatment of timber used in contact with the ground or in water.

Presumably the floating collar which had been mentioned was more in the nature of a remedial measure and not primarily a method of preservation, except perhaps in the peculiar circumstances which arose in Australia and which Mr Ley had mentioned.

The Australians had the Author's deepest sympathy in the field of preservation. Though they had a large number of eucalypts which were particularly durable, those were in shorter supply than they had formerly been, and Australian engineers were therefore having to turn to secondary timbers or other eucalypts, which were not so durable, and they were faced with the problem of devising some method of impregnating these very refractory timbers. The Australian Laboratory were at present experimenting with very high pressures. They had designed and were carrying out initial treatments at pressures of 1,000 lb. per square inch, whereas normally in Great Britain pressures did not exceed 200 lb. per square inch. It had been possible to do that because those eucalypts were very strong timbers and would withstand very high pressures of that order, whereas

Douglas fir and other timbers might be damaged even at pressures as low as 200 lb. per square inch.

He had not come across the Italian method to which Mr Ley had referred, but he suspected that it was an idea for re-using old poles. He had seen something similar in Canada, where they had cut off the decayed butt of a pole and used a similar type of support to give extra height rather than to avoid decay at ground level.

The Author feared that he did not know the answer to Mr Saurin's question concerning gribble attack, and had not enough experience to say whether what had been found was typical or not.

The evidence as to where marine-borer attack mostly occurred was somewhat conflicting. It had been generally stated that *Limnoria* attack was greatest near the surface, that was, between low-tide and half-tide levels, whereas *Teredo* damage was most severe at the mud-line. Both borers were in fact found at all depths down to the mud-line.

It had been reported by F. G. Walton Smith of the Marine Laboratory, University of Miami, that he has found at Miami that attack by both *Limnoria* and *Teredo* on test panels near the bottom was about three times greater than that on panels located near the surface. Recently, G. Owen of Glasgow University, in a letter to *Nature*, had stated that on examining piles in Loch Ryan he had found that *Teredo* attack was severest near the bottom and in raker piles also in the under and more dimly lit portions.

The Author thought that Mr Duvivier had been misinformed regarding supplies of ekki. That and other suitable West African hardwoods were in plentiful supply and were likely to remain so in the future. The Author agreed that for certain forms of coastal defence work, such as groynes, where abrasion was particularly severe, pressure-treated softwoods were not so suitable as naturally durable hardwoods which were also resistant to that form of deterioration.

In reply to Mr Dath, all types of wood preservatives were used for internal work, but in practice the choice was usually determined by such factors as the kind of finish required. Protection against wood-boring insects was usually obtained with the solvent-type preservatives, and those containing pentachlorophenol, copper naphthenate, chlorinated naphthalenes, and benzene hexachloride were successfully used. Since those preservatives did not cause swelling or raising of the grain, they could be used for finished woodwork. Internal structural and flooring timbers were often pressure-treated with creosote or a water-borne preservative.

Correspondence

Mr M. G. J. McHaffie observed that although the Author had stressed the necessity for timber to be impregnated with an antiseptic as deeply and uniformly as possible if it was to be preserved against decay, nowhere in the Paper was there any reference made to incising. It would be of

interest if the Author would state his reasons for that omission, and advance any arguments he might have for and against incising.

Mr McHaffie confirmed from his own experience the Author's statement that timber kept out of contact with air would not be subject to fungal decay. For instance, round fir uncreosoted piles supporting a brick building, the heads of which had been driven below the level where the surrounding earth could become dry, were found to be in excellent condition after many years.

Mr McHaffie was interested in the Author's reference to timber in large sizes being more resistant to fire than steel or metals because only the outer layers were burned. When in Bremen in 1926, Mr McHaffie observed that the structural members of the brick-built transit sheds and the warehouses behind them consisted wholly of timber. Upon enquiring the reason for that, he had been told that it was a precaution against fire! It appeared that a serious fire had occurred in one of the earlier buildings, the structural members of which had been of steel, and some firemen had been killed by the sudden collapse of stanchions and roof. As a result of that experience, the German engineers had decided to adopt large-section wrot-timber members from which the arrises were removed by a heavy chamfer, the theory being that whilst wrot and heavily chamfered timber would char under the action of fire it would not ignite.

Mr McHaffie supported the Author's plea to engineers under the heading "Conclusion," and advocated that wherever possible the timber should be worked and fitted before it was creosoted. At Southampton the larger ships were berthed alongside floating dummies (known in Admiralty circles as "catamarans"). They might be as large as 30–40 feet long by 12 feet wide and 6 feet deep, and were made of soft wood, such as Douglas fir or the like. It had been found of considerable advantage completely to frame and bolt-up the dummies, mark them for re-assembly, and then take them apart to be sent to the works for incising and creosoting; when they returned for re-assembly no cutting tool was used on them.

In timber jetties, the most expensive maintenance item was the replacement of the piles. Some years ago Mr McHaffie had designed a timber jetty, using greenheart piles, which were highly resistant to attack from *Limnoria* with which the water was infested, and creosoted Douglas fir for the transoms, walings, stringers, and bracing. All the latter had been bored and fitted to the greenheart piles after driving, marked for re-assembly, taken apart, and sent to the works to be incised and creosoted. An examination of the jetty 15 years after completion had shown that the creosoted timber was in an excellent state of preservation.

The fitting, taking apart, and re-assembly was obviously somewhat more expensive in first cost, but was undoubtedly a long-term economy.

The Author, in reply, remarked that Mr McHaffie was obviously one of the enlightened engineers and fully realized the importance of avoiding cutting and boring timber after it had been creosoted.

Mr McHaffie was also right in drawing attention to the need for incising prior to treatment when refractory timbers such as Douglas fir were used. Incising was necessary if deep and regular penetration was to be obtained with sawn Douglas fir. That necessity was, of course, avoided if round piling was used.

The Author's only reason for not mentioning incising had been that the object of the Paper had been primarily to stimulate interest in wood preservation, and without making the Paper long it had not been possible to deal fully with the technique of impregnating timber.

Correspondence on the foregoing Paper is now closed and no further contributions will be accepted.—Sec.I.C.E.

ORDINARY MEETING

19 May, 1953

HENRY FRANCIS CRONIN, C.B.E., M.C., B.Sc.(Eng.), President, in the Chair

The Council reported that they had recently transferred to the class of

Members

HODGSON, JOHN FORBES METCALFE.
HUTTON, THOMAS EDWARD, B.Sc. (*Manchester*).
VICKERS, WILLIAM HENRY, M.B.E.
YULE, THOMAS, M.Eng. (*Liverpool*).

and had admitted as

Graduates

ALDER, JOHN FREDERICK, B.A. (*Cantab.*), Stud.I.C.E.
ALLSOPP, PHILIP ANDERSON DESMOND, B.Sc. (Eng.) (*London*), Stud.I.C.E.
ANDERSON, DOUGLAS BRUCE, B.E. (*Adelaide*).
BARKER, JOHN ARTHUR, B.Sc.(Eng.) (*London*), Stud.I.C.E.
BURKE, KERRAS, B.E. (*Sydney*).
BURT, ROBERT COOPER BURGON, B.Sc. (*Edinburgh*).
CARPENTER, GEOFFREY ERIC, B.Sc.(Eng.) (*London*).
CLEMENT, DAVID BERNARD, B.A. (*Cantab.*).
CRAWFORD, ROBERT JAMES DEREK, B.Sc. (*Belfast*).
DAILEY, ARTHUR JOHN HUGH, B.Sc. (Eng.) (*London*).
DIAS, PONNAHENNEDIGE NAGESHA KAMAL, B.Sc.(Eng.) (*London*), Stud. I.C.E.
ELPHINSTONE, JOHN.
GENEROWICZ, BOHDAN SEDZIMIR, B.Sc. (Eng.) (*London*).
GORMAN, JOHN, B.E. (*National*).
GRAY, ANDREW MUNRO, B.Sc. (*Glasgow*), Stud.I.C.E.
GREEN, PETER BRIAN, B.Eng. (*Sheffield*), Stud.I.C.E.
GRIFFITH-JONES, ROBYN, Stud.I.C.E.
HAGEN, HELMUTH SIEGFRIED FRANÇOIS, B.Sc. (*Cape Town*), Stud.I.C.E.
HANDS, GRAHAM REGINALD, B.Sc. (*Wales*), Stud.I.C.E.
HARRISON, DAVID ALLEN, Stud.I.C.E.
HILL, MICHAEL JOHN, Stud.I.C.E.
KERR, JOHN, Stud.I.C.E.
LEWIS, WILLIAM MURRAY, M.A. (*Cantab.*), Stud.I.C.E.
MACDONALD, ALEXANDER THOMAS.
MOFFITT, DENIS PATRICK, B.A., B.A.I. (*Dublin*).
POWELL, GEOFFREY OWEN, B.A. (*Oxon.*).
PRITCHARD, JONATHAN, B.A. (*Cantab.*).
RAJANATHAN, KIRUPANANTHAN, B.Sc. (Eng.) (*London*).
SHAPLAND, CHRISTOPHER ROBERT, Stud. I.C.E.
SKINNER, JOHN EDMUND, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
SMITH, GRAHAME DUGDALE, B.Sc.(Eng.) (*London*), Stud.I.C.E.
SMITH, RAYMOND FREDERICK JAMES, Stud.I.C.E.
SMITH, ROBERT WAYNE, B.Sc.(Eng.) (*London*).
SMYTH, JOHN, B.Sc. (*Belfast*).
STEWART, PETER FRANCIS JAMES, B.Sc. (Eng.) (*London*).
TAYLOR, GEORGE ROBERT DESMOND, B.A., B.A.I. (*Dublin*).
TRUSCOTT, RICHARD PHILIP, Stud.I.C.E.
TURNER, DONALD, B.Sc.Tech. (*Manchester*).
VERDON, GEORGE FREDERICK, B.Sc. (Eng.) (*London*), Stud.I.C.E.
WATTS, RODERIC CRESSOR, B.A., B.A.I. (*Dublin*).

Wheatley, Gerald, B.Sc.Tech. (*Manchester*).
Whitehouse, Stanley Owen, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Wilson, James Marr.
Wolstenholme, Derek Robert, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Wright, Colin, Stud.I.C.E.

and had admitted as

Students

Andrews, Jack.
Atkinson, Ronald.
Bampfylde, Austin Peironi.
Baughen, Alan John.
Bevan, John Gower.
Brown, Keith David John.
Carss, Arthur Derek.
Carter, Henry Brian.
Curtis, William James Cormack.
Davies, Ashwynne.
Deacon, John Robert.
Dudeney, Donald Frederick.
Dunn, Graham William.
Ekhandamoorthy, Thangavelu.
Forster, Gordon Kaye.
Grayer, Roger James.
Guha, Amitabha, B.E., B.Sc. (*Calcutta*).
Heins, Howard George.
Henderson, David Sinclair.
Linney, Peter.
Macefield, John Gwyn.
McKenzie, Hugh Borland.
Marshall, Gordon Scott.
Morris, Edward Pryce.
Ong Kok Ho.
Pickering, Gerald.
Ratnaweera, Ariyadasa.
Smith, Stephen Faure.
Sposito, Brian.
Sumner, David Lynn.
Thompson, Athol James Patrick.
Tollick, Francis Campbell.
Ware, Allan Maurice.
Watson, Ronald.
Wilken, John Derrick.
Willits, Harold.
Woodhouse, James.
Yuan Tao Ming, B.Sc.(Eng.) (*Hong Kong*).

JAMES FORREST LECTURE, 1953

The President said that the Lecture about to be delivered had been founded to commemorate James Forrest, who had been Secretary of the Institution from 1859 to 1896, and afterwards Honorary Secretary until 1917, so that he had given altogether in those two positions a service of 58 years to the Institution. The James Forrest Lecture had been established in 1891 at his wish, and the original endowment had come from the balance of some money which had been subscribed to provide his portrait in the Institution. The portrait was now in the North Reading Room. To that sum James Forrest had added a similar sum.

The Lecture was the 59th of the series. It was to be given by Professor Levy, M.A., D.Sc., who had had a distinguished career at the Universities of Edinburgh, Oxford, and Birmingham. During World War I he had been a member of the Aerodynamics Research Staff at the National Physical Laboratory, and since 1920 he had been at the Imperial College. He had been Assistant Professor of Mathematics at the Royal College of Science, and subsequently Dean of the Royal College, and he was now Head of the Department of Mathematics. He had published many Papers on many subjects.

Professor Levy had chosen for the James Forrest Lecture the subject "The Impact of Statistics on Civil Engineering."

The Lecture was then delivered.

"The Impact of Statistics on Civil Engineering"

by

Professor Hyman Levy, M.A., D.Sc.

It was with considerable trepidation that I accepted the Council's invitation to deliver the James Forrest Lecture—not that I am ignorant of the whims and fancies of engineers: for the greater part of my life I have moved and breathed among them—at least, those of the academic sort. More than most mathematicians, I have given much thought to the educational needs of engineering students, and close attention to the views and experience of my engineering colleagues. I owe them much. They have educated me. On the other hand, I am well aware of the diffidence that overcomes theologians, men of arts, chemists, biologists, and even some engineers, in the presence of mathematicians. Now, however, it is I who have walked into the lions' den; I who face my audience with fear and trembling. I am only a mathematician who knows that to talk mathematics in public is to be guilty of an obscenity; and I am ignorant of engineering. I can disarm you only by being frank about my ignorance

and by asking forgiveness for the sins I am about to commit. What I have to say may be only of academic interest. It may even be hopelessly misguided.

Perhaps I am talking to the converted. It is likely that everything I have to say has already been said and better said by the engineers themselves. After all, they have to have their feet on solid ground; the demands of practice, on the scale on which engineering is practised today, not only prevent the engineer from making any serious blunder, but forces him to use every weapon, every tool that may be required to resolve his problems. It is worth remembering that it was Hazen, an American civil engineer, who in 1916 invented probability paper that gives all the constants in the Gaussian distribution in easily recognizable form. He was concerned with the run-off of drainage, and with considerable vision saw that the most reasonable variation to take for his figures was three times the standard deviation. In this he was absolutely up-to-date. It was the practice of his profession that forced him into the realm of statistics.

It is now more than 30 years since I first realized the importance of an understanding of statistics for the scientist and therefore also for the engineer. Now no student in any branch of engineering or of science who passes through the Imperial College of Science can do so without some understanding of the subject. Physicists, chemists, biologists, chemical engineers, all now lean upon it to interpret their results, and the revolution that has taken place in the design of computing machinery has placed the handling of large masses of data on the same level of facility as was the case with the slide-rule for simple operations a generation ago. Statistical studies have come to stay.

The significance of statistics lies both in its philosophy and in its practice. To assert as one does in any science that the *same* experiment under the *same* conditions always gives the *same* result is to propound a basic principle of scientific method. The object of any experiment—at least, one of its necessary objects—is to find the conditions under which an experiment is repeatable and its outcome verifiable. Like a machine, it must keep on doing the same thing over and over again. A good machine is the perfect controlled experiment. Without this there would be no feeling of certainty in the application of its findings, and indeed no science. The power of prophecy which is the great achievement of the scientist rests on little more than the fact that he has done the experiment before, knows the answer, and knows that it is consistent with other answers. And yet a moment's consideration suffices to remind us that no experiment is ever repeated. It is always a *different*, but a rather *similar* experiment; we may conveniently ignore the differences on occasion and concentrate on the similarities. So much so that if we get a rather different result on a later occasion, we airily blame it on "experimental errors," as if the first occasion gave the experimental truth and nothing but the experimental truth. There are no experimental errors—other than direct blunders

like writing one and one are three. There are simply experimental results of varying degrees of consistency or discordance. If we do not get a certain kind of consistency in the results we have not yet found the scientific experiment. If we do not get a certain degree of discordance a miracle will have happened. If a student, set the task of determining Young's Modulus for a wire, were to get exactly the same answer six times in succession one would know there was something wrong with the student. If, however, having obtained six slightly discordant results, he were to tell me that Young's Modulus was the average of the various values, I would know that he was giving me a new definition of Young's Modulus. If the experimenter concentrates on the *samenesses* of these numbers, as he would be doing, and brushes their differences aside, I would know he was a practical man anxious to represent a quality like the elasticity of a piece of material by one number and one number only. If he begins to study and analyse the *differences* between the numbers, to find how they are spread and to find a measure of their spread ; if he tells me that the probability of getting such-and-such a number on the next occasion is so-and-so, I would know he is a statistician. If he tells me there are no really repeatable experiments, no two objects or circumstances identical, no quality that can *always* be represented by a unique number ; if he adds that nevertheless there are circumstances in which it is sensible to use a unique number, and that there are others in which the group of numbers must be taken, then I will know that he is a practical man, a scientist, a statistician, and a philosopher. To know that no quality is sharply and uniquely defined, that every quality is of a blurred statistical nature is of first importance to the man who represents it by a single number. That, of course, is why he plays for safety factors—coverage—seeking to insure himself against the dangers of diversity from which he finds it easier to turn his face. It may not be necessary for a practising engineer to be an adept statistician—that will depend on what kind of engineering he is practising—but he can certainly be a scientist and a philosopher and be the better engineer for it. To know the limitations of the field in which one is working is to be conscious of the possibility of overthrowing these limitations and to be the more understanding of what one is doing. It is the first essential in research.

These were some of the philosophical points that urged me 30 years ago to introduce the study of statistics for the students who passed through my hands. Today the whole field of production engineering and scientific management is shot across with statistical techniques, methods of locating variations in the quality of articles in mass production and of isolating the sources of these variations. The hand at the bench plots the points on the quality-control chart, and the selenium eye searches out the articles that exceed the bounds of tolerance. The marriage of statistics and engineering in quality control is a permanent union that cannot now be dissolved.

What, you may ask, has all this to do with the civil engineer ? He does

not produce Mersey Tunnels or Sydney Harbour Bridges on a conveyor belt. His is not the problem of mass production, of controlling the stability of flow of standardized commodities. There is only one Sydney Bridge, one Mersey Tunnel, one Aswan dam. The civil engineer is concerned with uniqueness, individuality, very special circumstances, and that is why the experience in a civil engineering firm is so valuable. It covers such a wide diversity of unique undertakings. There are two points to be noticed here. Everything is of course unique. Uniqueness is ubiquitous. It is the most common of all qualities and civil engineers are not unique in thinking that their products are unique. Mathematicians are terribly unique. The second point is that if each task undertaken by the civil engineer is as unique as all that, there would be no possibility of integrating such tasks into a valuable experience. Each unique undertaking becomes itself a prototype for a class and a class is unified through its similarities. You meet at this Institution because you have a special kind of uniqueness in common. As always, clarity demands that we ask the same pair of questions as was asked in connexion with the measurement of Young's Modulus—in what sense are these tasks the same and in what sense are they different ? There must be qualities common to all bridges, however unique, that could be studied from statistical data. They all span gaps, they rest on foundations, they carry traffic loads, they are subject to weathering, to wear and tear, to shifting of their foundations. Once they are fixed in position they refuse to budge. They canalize traffic for a generation. They have social effects. They influence the direction of roads, the building of structures along these roads; they affect road accidents, trade, and commerce. Social changes affect them. They begin to bear loads they were not designed to carry as changes occur in road transport. They are shaken and rattled by modern traffic until their very safety factors fall loose ! These and a thousand other matters teem with statistical problems. No doubt every one of these problems is very special to the special bridge and in that sense is a unique problem, but who would assert that there are not general conclusions to be drawn of which these particular bridges are individual illustrations ? In fact, we have just made use of one of a very general nature that at least helps us to see the problem in a certain perspective. The engineer designs to a given specification, and within this designs his structure to be sufficiently strong to carry through its functions as laid down. It may be a bridge, a school, a factory, a railway terminus in the centre of a large city. If the original plan contemplated an active functional life of 30 years without explicitly mentioning it, the engineer—for safety—designs it to last for 50, also without explicitly mentioning it. But schools and railway termini have social functions which change rapidly. Education changes under the impact of experience. The power units of railway stock are revolutionized. The school becomes a monument of a past educational policy now dead and interred. I live and work in a building precisely like this, which even

the bombardment of the last war could not shake. The hard shell in which we grow cabins us. We are perpetually waging a struggle of content against form. The railway terminus stands as a reminder of a past mode of locomotion, immune to the demands of an oil, an electrical, or an atomic age. The heavy solid buildings that face each other a few yards apart on opposite sides of the Cornhills and Leadenhall Streets of our major cities look down grimly and unrelentingly at the congested mass of modern transport that inches its way along as its mobility is frustrated by the immovable obstacles these buildings themselves represent. Study the statistics produced by the transport authorities and you will realize how important is time. In another 5 years, at most, unless a bold and inspired government will seize a bulldozer and flatten out these monuments of architectural and engineering antiquity, burying beneath them the vested interests that cling to their foundations, and driving a broad highway through our Cities of London, the marvellous achievements of the mechanical engineer in the realm of transport will be choked to death in our public thoroughfares; cars and buses will be banned from these areas and we shall be compelled to return to the horse and the hand-barrow. This fundamental contradiction between the enduring permanence of civil engineering structures on the one hand, and the rapidly changing content of mechanized transport on the other, is the operative destructive principle that has never been resolved. It is converting our centres of activity, our urban civilization into areas afflicted with a creeping paralysis. Political parties may wrangle over the advantages and disadvantages of nationalization or private enterprise, but in neither of their balance sheets does this great loss in social productivity show to its full extent. No building yard, however small, would bear such a bottleneck inefficiency for five minutes. Are we to say that a civilization that possesses the ingenuity and the scientific and engineering power to blot out our cities cannot arouse itself to the point of clearing away its civic obstacles? This is one of the great and critical contradictions of our urban life, and it emerges out of the unco-ordinated functions to two major branches of engineering. A ship lasts a generation. Its machinery is then outdated and its hull unreliable. It is towed out of the mainstream and broken up, to be replaced by its modern equivalent. An airliner of yesterday is today outmoded; but a civil engineering structure with its feet well planted and reinforced by its factors of safety towers like timeless Olympus above the swirling chaos of grinding gears that pay cacophonous tribute to the immovable and everlasting gods that direct their course. But it is a tribute of self-immolation. Delicate machinery, designed to give high performance on a straight clear highway, is compelled to operate under conditions that bear not the slightest resemblance to those of the design. Are we now to witness new designs of vehicles that operate most effectively when in slow motion? I am reminded of the situation during the war when electric lamps produced after the most searching research to give

greatest efficiency were then painted over so that their illumination could be reduced to vanishing point.

It is easy for the civil engineer, the architect, and even the mechanical engineer to shrug their shoulders and to say that it is not their business. They work to specification and they cannot go behind that. But the fact remains that they, better than any other section of the community, can appreciate the enormity of the social stupidity that is being perpetrated in every large city. These, what might be called the external relations of civil engineering, teem with urgent problems of change and decay, of internal contradictions in development that call for the closest statistical scrutiny. On this side, civil engineering merges easily with what might be called civic engineering, which must work on a network of statistical information. Can the civil engineer incorporate time into his designs ?

These remarks touch some of the consequences of regarding civil engineering as an activity in a social vacuum. But there are others. The contradiction I have referred to is itself frustrating the fullest development of your own subject. If a giant bulldozer does indeed sweep a broad highway through the centres of our great cities to release the panting engines to pursue their unimpeded way, what new vistas are opened up of new roads, new bridges and viaducts, new factories, and indeed new changes in the surface geography of the country. If production engineering is the child of the marriage of mechanical engineering and statistics, then the new phase of civic and civil engineering will emerge out of the union of civil engineering with statistics—provided, of course, that the understanding that grows from this communion is translated into social practice. Of much of this most of you are, I am certain, very conscious. Those, for instance, who are speeding forward the cause of public health engineering are already alive to it.

But it is by no means my purpose on this occasion to press this external aspect of our problem. It is sufficient if I have made the point that, in spite of the individual uniqueness of engineering structures and the diversity which they show as a group, there are features which they possess in common ; and that these features are rapidly becoming of major importance to the community and to yourselves as engineers.

Now therefore let us turn to what I would call the internal relations of your subject, and again take up this question of uniqueness. The engineer produces his drawings to meet the prescribed specifications, and hands them over to his constructional colleague. The outcome is this unique structure. It has its own special features. There is no duplicate anywhere. It is the only one of its kind. How then can a statistician possibly deal with a single entity ? Your design and the associated calculations are based on certain tests, the results of which have been used in designing each member of the structure. Piers, girders, rods, ties, nuts, bolts, all are believed to be able to stand up to certain loads or stresses, as the case may be, before they will collapse under crushing or under tension. But have you tested

these individual members you are actually using in this structure? Of course not. They would have had to be tested to destruction. You have only tested objects like these. Very well, if you yourself insist that this is a unique structure, what do you know of this unique thing you have constructed? What can you know of these particular elements that you have used and have not tested? Practically nothing. Here and there you may have subjected a joint to an X-ray examination, but that is by no means the same thing. You build, in fact, on hope. You build a bridge of untested parts. You do more. You test the parts of an unbuilt bridge. You cannot do otherwise. On this topsy-turvy basis you are finally satisfied that the public may risk its life for a generation or two on the one that was actually built. It is an extraordinary situation. What is more extraordinary is that your hope turns out to be well founded—too well founded, to judge from what we have been talking about a few minutes ago. The bridge stands.

You can now see what I mean. A concrete pillar, for example, may crush at loads between 3,000 lb. per square inch and 7,000 lb. per square inch. There is not a unique crushing load for every element in a concrete structure. Each pillar used is, as it were, a sample selected from a set, with this variation in crushing load, and together they constitute just this structure. No doubt the *design* as a whole is unique, but from that unique design an enormous number of structures might have been built to satisfy its requirements, and each member of the set of such structures would have shown a different total performance. You have selected just one out of this set. That is how uniqueness and uniformity are reconciled. What are the chances, the statistician might ask, that the actual one constructed was the weakest of the lot—that each element chosen was the one that would crush at the lower limit of load? Furthermore, what are the chances that the *structure* as made will now fail at the lower limit? Not very likely, you say. Perhaps not—we shall see—but how likely? What is *its* probability? Among all the potential structures satisfying the requirements of the design, where among the set does this actual one lie? What, as it were, is its security figure? What is the probability of its collapsing at various loads? You may argue, of course, that your factor of safety enables you to brush this aside because on every occasion, for each element, you design as if collapse in the material would occur at the lowest level when, of course, it will not. I say that this does not meet my point, for two reasons. First, every attempt to determine more precisely how loads are distributed, and what the effects of these are, is itself a step towards helping us to reduce the factor of safety with some sense of security. You can, of course, always make a structure so strong that it will be able to face all probable eventualities for the next thousand years, but that, as we have seen, would be a crime against the community. You would be erecting a permanent monument to yourself. It would also be unscientific and unaesthetic. Instead of asking, therefore, what is the probability of failure of the whole

structure at various loads, I can ask an equivalent question which may force you to explain the meaning of your factor of safety in other terms: what is the probable life of your structure? When will your factor of safety become dangerously low? This brings me to my second reason for asserting that the "factor of safety" answer is not adequate. An engineering structure, unlike a living being, comes fully-fledged into existence. It is usually at its strongest at birth. Thereafter it begins to degenerate, either because its foundations shift, for statistical data on which we must turn to the soil engineers, or because of the influence of atmosphere and climate, and there we need the chemist and the meteorologist, or—more likely—because society makes greater demands on it than were anticipated on its erection. By coming into existence it encouraged society to step up its demands. Today our roads and our bridges are hammered by a succession of heavily laden lorries running nose to tail in both directions. Be sure that any weakness in construction will be found out quickly enough. Additional strength in one member does not necessarily compensate for a deficiency in another. That will depend on the nature of the structure. Now suppose your civic engineer, with his eye to the future, decides to lay down an *upper* and a *lower* limit to the safe life of the bridge, how would this alter your handling of the problem of design? Precisely what role would your factor of safety now play? I pose the problem in this way precisely because this kind of question is intimately associated with the considerations I raised earlier regarding the permanence, as opposed to the fluidity, of engineering structures. Can civil engineering cope with the changing needs of society?

I am not asking for omniscience. Ignorance we must always have with us, but a statistical study of some of these factors may throw a considerable light on a few of our more complacent assumptions of uniqueness and permanence and even lead us to a more precise formulation of our problems. Let me illustrate with a simple and elementary case. For this purpose I should like to use some data I have had an opportunity of assembling.

A set of 212 6-inch cubes of concrete was collected on a constructional site where mixing was taking place under what were presumed to be uniform conditions, and the cubes were allowed to set for periods of varying duration ranging from 7 to 28 days and more. Those that were crushed at 28 days numbered 38. The values so obtained formed one collection. The values obtained from the others, crushed at other dates, were extrapolated to 28 days, using the standard curve for the gain of strength of concrete with maturity, at constant temperature. The first question to which the statistician desires an answer is: how valid is this extrapolation? Can the collection of 174 extrapolated numbers be regarded as reasonably belonging to the same collection as the remaining 38, which were actually tested at 28 days. For this purpose the so-called t-test is applied to the two collections. The results are given in Table 1. We should notice that the figures have been grouped into intervals of 500 units, each unit

Table 1

X is the breaking strength of a sample of concrete (6-inch cube) after 28 days.
Grouping interval = 500 units.
X is the central value of the interval.

To Compare the Means of Two Samples.
(1) Sample of size 38. Actual observations—column f_1.
(2) Sample of size 174. Extrapolated values—column f_2.

Construct a new variable Y where $Y = \dfrac{(X - 5{,}300)}{500}$ and do all the calculations using the new variable.

Y	f_1	f_2	Yf_1	Yf_2	Y^2f_1	Y^2f_2	X
−6	2	0	−12	0	72	0	2,300
−5	0	1	0	−5	0	25	2,800
−4	1	2	−4	−8	16	32	3,300
−3	2	12	−6	−36	18	108	3,800
−2	6	28	−12	−56	24	112	4,300
−1	4	35	−4	−35	4	35	4,800
0	9	26	0	0	0	0	5,300
1	9	23	9	23	9	23	5,800
2	4	31	8	62	16	124	6,300
3	1	12	3	36	9	108	6,800
4	0	1	0	4	0	16	7,300
5	0	3	0	15	0	75	7,800
	$n_1=38$	$n_2=174$	−18	0	168	658	

μ_1 denotes mean value of Y in sample size 38 = − 0·473 (actual observation)
μ_2 ,, mean value of Y in sample size 174 = 0 (extrapolated values)
s_1^2 ,, variance of Y in sample size 38 = 4·196 (actual observation)
s_2^2 ,, variance of Y in sample size 174 = 3·781 (extrapolated values)

Weighted combination of variances = s^2 $= \dfrac{37s_1^2 + 173s_2^2}{210}$

$= 3{\cdot}854$

$$t = \frac{(\mu_1 - \mu_2)}{s\sqrt{\dfrac{1}{n_1} + \dfrac{1}{n_2}}}$$

In this case, therefore, $t = 1{\cdot}374$.

This value of t occurs by chance with a probability of 17 per cent.
The hypothesis that the two samples came from the same population cannot be rejected.
Significant level = 5 per cent.

representing a compressive load of 500 lb. per square inch. This gives a range of twelve intervals. Merely for convenience in calculation a new variable Y is introduced in place of X the compressive load.

The results show that :—

- average crushing load for those tested at 28 days is 5,064 lb. per square inch ;
- average crushing load for those extrapolated to 28 days is 5,300 lb. per square inch ;
- the standard deviation of those tested at 28 days is 1,025 lb. per square inch ; and
- the standard deviation of those extrapolated to 28 days is 975 lb. per square inch.

These figures raise immediately an important statistical issue. The question is whether such differences in average and in spread could have been obtained by accident with a reasonable probability by choosing two samples of 38 and 174 respectively from the same body of data.

The calculation for examining this question by the relevant t-test is shown in Table 1. This tells us that the differences in average and in standard deviation found in the present case would arise in at least 17 per cent of cases. Since the borderline of significance is usually taken to be 5 per cent, this implies that we cannot reject the assumption that those actually tested at 28 days and those extrapolated to 28 days belong to the same set of statistical data. To that extent we are entitled to regard this as a verification of the method of extrapolation. So henceforth we will use the whole collection of data as one group. Has the statistician been too meticulous here ?

Actually they show a crushing load that ranges from 2,177 lb. per square inch to 7,600 lb. per square inch, but well over 80 per cent of them are to be found in the range 4,300 to 6,300. They are, of course, site values, and no doubt under controlled laboratory conditions they would have been much more uniform. Nevertheless they must be accepted as representative of the concrete actually used. Variations in moisture content of the sand that arrives on the site, and the sometimes rough-and-ready methods of compensating for this, are bound in practice to lead to wide variations in ultimate strength. The fact is that the operatives are really carrying through the functions of a chemical technologist on the site. In these circumstances, it is useless to talk of errors in mixing and so on. These figures represent the final stage of the concrete as actually used. That is what I meant earlier by saying that there are no errors of experiment ; there are only results.

Out of these tests a new series of questions now arise. With an elastic material such as wood or metal, a test on a small specimen can be immediately interpreted in terms of the larger beam. The material is homogeneous and the behaviour is similar under compression to that under

tension. With concrete apparently the situation is different. There is nothing that corresponds to a coefficient of elasticity except under very restricted conditions. The material is much weaker under tension than under compression. Hence the need for prestressing. For this reason also, concrete engineers prefer to deal with loads rather than with stresses. I am given to understand that under a compressive load, pieces from the side of the compressed block usually disengage themselves, crack off or flake off, from the main mass as crushing begins. This seems to me to suggest that vertical loading is accompanied by horizontal tension, and that on crushing there is failure under tension horizontally in one or more weak regions. I do not know how far the physics of such a relatively coarse-grained material as concrete has been explored, but this possibility of a heavy compressive force in one direction giving rise to a heavy localized tensile force at right angles seems not unlikely. Failure would then occur catastrophically in both directions. I confess that this is almost pure speculation because I have no evidence to go on, but it appears at least to be a reasonable initial hypothesis. Moreover, we would expect such failures to be associated with the occurrence of weak spots at or near the exposed surfaces and we can tentatively take the measure of the greatest weakness on the sides of a unit cube as a function of the load at which the unit cube crushes. On this assumption, any piece of concrete may be regarded as showing a statistical distribution of surface weak spots of random occurrence. Test pieces, with a small surface area, will then contain a small sample of this population of weak spots, and those with a larger surface correspondingly larger samples. The probability that the larger surface will contain a weak spot that will contribute to crushing under a given load will therefore be greater than with the smaller surface. This would argue that the crushing load would depend statistically on the surface size of the specimen tested, and, as the area of the surface increases, would tend towards the lowest value of the crushing load found among the unit specimen cubes tested. This may be regarded as a kind of statistical effect. Let us look at this more closely. Suppose that among a large number of unit cubes tested the lowest crushing load occurs with a frequency of 1 in m specimens. Since the exposed surface for a cube under vertical compression is 4 square units, this means that the weak spot corresponding to this crushing load occurs once in $4m$ square units, that is, $1/4m$ is the probability of its occurring in a given unit square of surface. The probability of its not occurring there is $1 - 1/4m$. The probability of it nowhere occurring in a stretch of n square units is therefore $(1 - 1/4m)^n$. Accordingly, the probability of its not not-occurring in n square units, that is, the probability of its occurring at least once, is $1 - (1 - 1/4m)^n$. Since we are thinking of the earliest load at which crushing occurs, a rare occurrence, m will be large. In the case of the 212 cubes we have cited, m was about 100. The term $(1 - 1/4m)^n$ is then approximately $e^{-n/4m}$. For example, if we take a pillar of 6-inch square section, 6 feet in height,

made from the concrete whose unit (6-inch) cubes were tested, then $m = 100$ approximately, and the exposed surface area is $n = 48$ square units. Thus the probability of failing at the lowest load found among the unit cubes is :

$$P = 1 - e^{-48/400} = 0{\cdot}12.$$

This seems to suggest that, on the average, 12 pillars out of 100 will fail at the lowest load for which the unit cubes failed. In the latter case it was 1 in 100. As the size of the exposed surface increases the probability of failure at the weakest load for the unit cube increases. We notice further that a pillar of circular cross-section is less likely to fail at the earlier load than one of rectangular section but of the same cross-sectional area, since it has a smaller surface area ; whilst a thin sheet of concrete of rectangular section—a wall, for example—is almost certain to crush at the lowest level.

If this result is even approximately correct we appear to be driven to the conclusion that when the engineer consoles himself by designing for safety, by assuming that a pillar will crush at the lowest load shown by the test cubes, there is in fact no special consolation in it. The pillar is not unlikely to fail there. The unit cube will not. Finally, the analysis suggests that measurements of crushing loads for pillars showing varying degrees of surface area for the same cross-sectional area, ranging from the circular to the narrow rectangular, might well be worth making, providing these were accompanied by a careful examination of the surface cracks and flakings that show themselves just as crushing commences. A knowledge of how to recognize a possible source of weakness by surface study might possibly be valuable.

We are now in a position to widen the scope of our discussion to some extent. Statistical groups divide themselves into two categories at least. Those of the compensating type are such that, the larger the sample, the more do the weaker members tend to be balanced by the stronger ; the longer rods make up for the shorter ones ; deviations from the average in one direction balance deviations in the opposite. This principle is implicit in the so-called Law of Large Numbers ; but it by no means covers all the possibilities. The qualities of a group may certainly vary with its size, and a small sample may not show the characteristics that would manifest themselves in a large population. The problems of traffic, for example, cannot be adequately studied for a large town by taking a sample village. In the case we have just discussed we have seen how the properties of the larger structure may be expected to differ progressively from those of the tested sample. As an extreme example, it is obvious that a premature explosion in a gunpowder factory will by no means be compensated for by a tardier explosion. There will be no average time of explosion. It is a case of all or nothing. A trigger system, one which is transformed when a single member of the system is transformed, we will call a catastrophic system.

Consider, for example, the case of two parallel concrete pillars A and B surmounted by a cross-beam carrying a load. We assume that if one pillar collapses, the structure collapses. It is in our sense a catastrophic system. Let us suppose from previous tests that we know the frequency or the probability of failure of each of the pillars at loads corresponding to $L, L+a, L+2a, \ldots L+ra, \ldots L+na$. Failure may be interpreted in any way we like, say, by actual collapse of one of the pillars, or by the appearance of surface cracks, etc. Let the probabilities or relative frequencies of failure just at these loads, and not before, for A and B respectively, be $p_0, p_1, \ldots p_r \ldots p_n$ and $P_0, P_1, \ldots P_r, \ldots P_n$. The structure as a whole will fail if either A or B fails or, of course, if both fail simultaneously.

Thus the probability that the structure will fail at load L is equal to the probability that A will fail at L but B will not fail at L, plus the probability that B will fail at L but A will not fail at L, plus the probability that A and B will both fail at L

$$\text{Prob.} = p_0(1-P_0) + P_0(1-p_0) + p_0P_0 = p_0 + P_0 - p_0P_0.$$

Probability that the structure will not fail until $L + ra$

= probability that A will fail at $L + ra$ and B will not fail before $L + ra$

+ probability that B will fail at $L + ra$ but A will not fail before $L + ra$

− probability that A and B will both fail at $L + ra$

$$= p_r[1-(P_0+P_1+\ldots P_{r-1})] + P_r[1-(p_0+p_1+\ldots+p_{r-1})] - p_rP_r$$

$$= p_r + P_r - p_r(P_0+P_1\ldots+P_r) - P_0(p_0+p_1+\ldots+p_r) + p_rP_r$$

$$= p_r + P_r + p_rP_r - p_r\sum_0^r P_r - P_r\sum_0^r p_r.$$

The final term occurs for $r = n$, in which case the two summations each become unity, since they are the sum of the probabilities, and consequently the expression reduces to p_nP_n.

This then solves the general case for two members of a composite structure. When the two members belong to the same statistical set so that $p_r = P_r$ these expressions reduce to :

Probability	$2p_0 - p_0^2, \ldots,$	$2p_r \sum_r^n p_r - p_r^2, \ldots,$	$p_n^2.$
Load	$L, \ldots,$	$L + ra, \ldots,$	$L + na.$

In illustration we shall use the data derived from the tests already found but in simplified form. Considerably more than 80 per cent of the tests give a crushing load between 4,300 lb. per square inch and 6,300 lb. per square inch, and the frequency of occurrence in intervals of 500 lb. per square inch between these limits remains fairly constant. This means that considerably more than 80 per cent of the unit cubes showed crushing with equal probabilities within this range. For simplicity, therefore, we

shall assume a probability distribution as follows. The actual figures may easily be substituted if necessary. The calculation for the two pillars follows from the formula.

lb. per square inch .	4,300	4,800	5,300	5,800	6,300
Probability of failure (single pillar)	$p_0 = 0{\cdot}20$	$p_1 = 0{\cdot}20$	$p_2 = 0{\cdot}20$	$p_3 = 0{\cdot}20$	$p_4 = 0{\cdot}20$
Probability of failure (two pillars)	0·36	0·28	0·20	0·12	0·04

Thus, commencing with a pillar which is equally likely to break anywhere in the 4,300-6,300 range, we now find that the mode, the most probable point of collapse, has shifted to the lowest point, and that 36 per cent of the double-pillar system may be expected to collapse there, instead of 20 per cent; whilst 74 per cent will collapse within the lower half of the range.

Following the same method we can now apply this to a four-pillar system, using the above results of the two-pillar system twice.

Probability of failure (four pillars)	0·590	0·280	0·104	0·024	·002

The position has become even more acute. If the four-pillar system fails when any one or more of the four pillars separately fails, 59 per cent of the composite structures will fail at the lowest load, and 92 per cent at loads in the lower half of the range. The danger point of most probable failure for the composite structure, moves inexorably towards the lowest failing load for the individual pillar.

It is not my purpose here to elaborate a theory of failure for concrete —I am not equipped to do that—nor to pursue the kind of study I have just touched on, into more elaborate structures. That would not be very difficult. All I am seeking to show can be embraced under two headings. First, as others have doubtless stressed before me, that concepts of probability must have a significant place in expressing the security of a member of a structure, and of the structure itself as a whole. Secondly, that the factual basis on which such a calculation must rest is comprised of a body of data which is of a statistical nature in so far as it is concerned with the properties of the materials used; and is of a statistically changing nature in so far as the functioning of the whole structure in society changes as it functions. It is all too easy for scientists, mathematicians, and artists to bring themselves to believe that their creations and their discoveries are independent of time and place, that in some sense these discoveries possess a universal validity and an unchanging interpretation. The civil engineer, caught up, as he necessarily is, in satisfying the needs of a changing society, cannot possibly isolate himself in an ivory tower of this nature. The temporal element must finally play a decisive role in his designs. Time must be of the essence of your contracts. It is therefore fitting that I should end on the single note, " Time, gentlemen, please."

Professor A. J. S. Pippard, in proposing a vote of thanks to the Lecturer, said that Professor Levy had made some very kind remarks at the beginning of his Lecture about what he had learnt from his engineering colleagues in a long life spent in teaching mathematics. Professor Pippard believed that he was the eldest survivor, or at least the eldest in active service, of those colleagues, and he wished to express their thanks to Professor Levy for his kind words and also to repay the compliment by saying that he had learnt a tremendous amount on the subject of mathematics and on other subjects from the Lecturer.

It gave him very great pleasure to propose a very hearty vote of thanks to his colleague, Professor Levy.

Mr H. Shirley Smith seconded the vote of thanks, which was carried with acclamation.

ELECTION OF MEMBERS AND ASSOCIATE MEMBERS

The Council at their meeting on the 22nd September, 1953, in accordance with By-law 14, declared that the undermentioned have been duly elected as Associate Members.

Home

Arrowsmith, Raymond, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Astley, Robert John, Stud.I.C.E.
Banham, John Victor David, Stud. I.C.E.
Barker, Anthony Wilton, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Barnett, John Charles William.
Bottrill, Clive, B.Sc. (*Manchester*), Stud.I.C.E.
Brain, Robert, M.Eng. (*Liverpool*).
Cooney, Eric George, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Dalman, John Barry, Ph.D., Grad. I.C.E.
Dennington, Dudley, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Dudgeon, Brian Christopher, M.A. (*Oxon.*).
Dykes, Alexander Robert, B.Sc. (*Glasgow*), Stud.I.C.E.
Evans, Dewi Ieuan, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Findlay, William Ogilvy, B.Sc. (*St Andrews*).
Francis, John Bernard, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Goad, Maurice Gordon, Stud.I.C.E.
Gossage, Brian, Stud.I.C.E.
Goudy, Alexander Porter, M.A. (*Cantab.*), Stud.I.C.E.
Gray, Thomas Frederick Norman, B.Sc.(Eng.) (*London*).
Greenlees, John, B.Sc. (*Glasgow*).
Hall, John Denis, M.A. (*Cantab.*), Stud.I.C.E.
Hayton, John George, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
Hellis, John Blackwell, Grad.I.C.E.
Hughes, Lionel Maurice, B.A. (*Cantab.*), Stud.I.C.E.
Hunt, Hugh Mackay, B.Sc. (*Edinburgh*), Stud.I.C.E.
Kay, Ronald William, M.Eng. (*Liverpool*), Stud.I.C.E.
Kirkby, Eustace Antony.
Knight, Vivian Albert, Stud.I.C.E.
Le Cesne Byrne, Bernard John Peter, B.E. (*National*), Stud.I.C.E.
Lemmon, Geoffrey David, Stud. I.C.E.
Longman, Donald James, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Lowe, James Neville, M.A. (*Cantab.*).
Macfarlane, George Keith Murray.
McKillen, Eric Raymond, B.Sc. (*Belfast*), Stud.I.C.E.
Mallett, Geoffrey Page, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Marwood, John Edmonds, Grad.I.C.E.
Middlemass, Robert Calder, B.Sc. (*Edinburgh*).
Moore, John Malcolm, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Murray, Andrew Robb, Stud.I.C.E.
Neill, Charles Robert, B.Sc. (*Glasgow*), Stud.I.C.E.
Pashley, Harold Arthur, B.Sc. (Eng.) (*London*), Stud.I.C.E.
Pearce, Kenneth Walter, Grad. I.C.E.
Platt, Walter John, B.Sc.Tech. (*Manchester*).
Readshaw, Edward Emerson, B.Sc. (*Durham*), Stud.I.C.E.
Rennie, Douglas Yorke, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Robinson, William Henry.
Robson, Vernon, Stud.I.C.E.
Rowe, Gerald, Stud.I.C.E.
Salt, Stanley Reginald, B.Sc.(Eng.) (*London*), Stud.I.C.E.
Selby, Arnold Godfrey, M.A. (*Cantab.*), Stud.I.C.E.
Short, Frank Edmund.
Shuttle, George William Charles, B.Sc. (Eng.) (*London*), Grad.I.C.E.
Spindel, Julian Erwin, B.Sc.(Eng.) (*London*), Grad.I.C.E.
Stiles, Terence Litchfield, Grad. I.C.E.
Stone, John Thomas, M.C., M.A. (*Cantab.*).
Stoneman, Frederick Denis William.
Storey, Gerald Francis, B.Sc. (*Edinburgh*), Stud.I.C.E.
Tasker, Leslie, Stud.I.C.E.

TATTERSALL, JOHN KENNETH, B.A. (*Cantab.*), Stud.I.C.E.
THURMAN, DERRICK, B.Sc. (*Manchester*), Stud.I.C.E.
TUDHOPE, PETER DOUGLAS, B.Sc.(Eng.) (*London*), Stud.I.C.E.
TYLER, RAYMOND GEORGE, B.Sc.(Eng.) (*London*), Stud.I.C.E.
VENABLES, DESMOND, Stud.I.C.E.
VIZARD, GEORGE LIONEL, Stud.I.C.E.
WATSON, RICHARD VICTOR, B.Sc.(Eng.) (*London*).
WHITEHEAD, FRANK BERNARD, B.Sc. (Eng.) (*London*), Stud.I.C.E.
WHITTLE, JOHN FREDERICK, B.Sc.Tech. (*Manchester*), Stud.I.C.E.
WILSON, HERBERT BERNARD, B.Sc. (Eng.) (*London*).
WILSON, WILLIAM BARRY, B.Sc.(Eng.) (*London*), Stud.I.C.E.
WYATT, CHRISTOPHER TERREL, B.Sc. (Eng.) (*London*), Stud.I.C.E.

Abroad

ABDULLAH, ABDUL HAMID BIN, B.A. (*Cantab.*).
BURRELL, RAYMOND WILTON, B.E. (*New Zealand*).
DOLLERY, AUSTIN STUART, B.Sc. (*Cape Town*), Stud.I.C.E.
EVANS, GUY LYCETT, B.Sc. (*New Zealand*).
EVANS, WILLIAM VICTOR, B.Sc. (*New Zealand*).
FRIIS, ERIK JUUL, B.Sc. (*Witwatersrand*), Stud.I.C.E.
GOODWIN, CHARLES PETER.
HAZELL, JOHN CARR, B.Sc.(Eng.) (*London*).
MILNE, RAYMOND JOHN, B.E. (*New Zealand*).
POWER, CEDRIC ARTHUR, B.Sc. (*New Zealand*), Stud.I.C.E.
WALLEY, EDWARD ARTHUR, B.Sc. (Eng.) (*London*), Stud.I.C.E.

DEATHS

It is with deep regret that intimation of the following deaths has been received.

Members

GILBERT ALFRED BALLARD, O.B.E. (E. 1912, T. 1934).
Sir BERNARD D'OLIER DARLEY, C.I.E. (E. 1906, T. 1931).
CHARLES EDMUND FONSEKA (E. 1932, T. 1947).
FRANK RICHARD FREEMAN, B.Sc.(Eng.) (E. 1916, T. 1928).
WILLIAM ARTHUR HARRISON, O.B.E., M.Eng. (E. 1927, T. 1937).
JOHN HOUSTON (E. 1928).
THOMAS HUMPHREY MATTHEWS, M.A. (E. 1935).
Captain (E.) WILLIAM ONYON, M.V.O. (R.N. Ret.) (E. 1926).
Professor HAROLD PERCY PHILPOT, B.Sc.(Eng.) (E. 1913, T. 1940).
JOSEPH NEWELL REESON (E. 1894, T. 1914).
PETER RUDOLF SWART, B.Sc. (E. 1940, T. 1952).
Lt. Col. HARRY WILLIAMSON (E. 1917, T. 1930).
JAMES WILLIAMSON, C.B.E. (E. 1907, T. 1923).
Sir JOHNSTONE WRIGHT (E. 1934).

Associate Members

HENRY WILFRID BARNES, B.Eng. (E. 1921).
FREDERICK THOMAS HARRISON (E. 1912).
CHARLES DELACOUR LE MAISTRE, C.B.E. (E. 1907).
DANIEL MACLEOD (E. 1918).
ROBERT CHRISTOPHER MELVILLE, B.Sc. (E. 1939).
RICHARD EDWARD MICHAEL (E. 1907).
RICHARD CECIL MOSS, B.A., B.A.I. (E. 1905).
VINCENT PACKER, M.C.E. (E. 1933).

CORRESPONDENCE
on a Paper published in Proceedings, Part I, January 1953

Paper No. 5843

"The Driving and Testing of Piles" †

by

Horace Denton Morgan, M.Sc.(Eng.), and
Charles Kenneth Haswell, B.Sc.(Eng.), MM.I.C.E.

Correspondence

Mr F. L. Cassel observed that estimation of the bearing capacity of piles by means of obtaining and using soil mechanics data was certainly not a perfectly satisfactory method, but was no worse than calculation from the pile-driving formulae. The best way was, no doubt, by driving a test pile and test-loading it. But even that method was no panacea, as had been proved by the Authors by the Abadan example.

Loading tests of friction piles were very valuable if they could be extended to clear failure. That was, of course, not often possible, and most of the loading tests described in the Paper had stopped short of such failure (if one took, as the uniformly accepted definition of the "ultimate bearing capacity," that load under which the pile failed progressively). The exception was the pile shown in *Figs 13*. Another purpose, short of that, was to prove that at working load the settlement remained within narrow limits and was progressing only at a constantly reduced rate.

It seemed to Mr Cassel that the loading tests carried out at Portishead B power station were of particular interest. The difference between the two types of pile was, of course, not due to their different construction but to their different dimensions. The statement about the variation of penetration appeared to be a misprint. According to Figs 17 and 18, Plate 2, it was the prestressed and not the precast pile which penetrated deeper by 2 feet, and that would be due to the greater weight of the precast pile (6 tons, compared with 3·35 tons for the prestressed pile); the 4-ton drop-hammer was too light to introduce sufficient energy into the 6-ton pile to overcome the resistance in the hard marl.

The observations at the loading tests appeared also to be attributable

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† Proc. Instn Civ. Engrs, Part I, vol. 2, p. 43 (Jan. 1953).

to the variation of dimensions. The cross-sectional area of the precast pile (point loading area) was 78 per cent larger, and the circumferential area (skin friction) was 30 per cent greater than those of the prestressed pile (112 square feet and 86·5 square feet).

Unfortunately no figures for the shear strength of the silt, clay, and marl had been given. Whilst it was in no way alleged that any definite calculation of the ultimate bearing capacity or the safe bearing load could be made, it was possible to make quite reliable first estimates.

Actually, some of the described piles, particularly the two at Portishead, could not be regarded as friction piles, but appeared to be point-bearing piles, the point load on the marl being reduced by some friction or cohesion. The settlement was predominantly of an elastic nature and was perhaps in small part attributable to consolidation. That was proved by the very large recovery rate. (Figs 17 (*a*) and 18 (*a*), Plate 2.)

The Abadan test piles were an excellent example for the often repeated, but seldom accepted, truth that a loading test of relatively short duration could not indicate the effect of long-term consolidation. Could the Authors provide some description of the soil profile at Abadan and the results of soil tests carried out (consolidation tests, index properties, size distribution)? Only the average shear strength had been mentioned, but that appeared insufficient for obtaining a complete picture. Since one could learn more from failure than from success, it would be useful if the missing description could be published.

Mr D. H. Cassidy observed that it was difficult to compare the results of the Authors' tests with one another and with the results of other experiments, owing to the lack of a standard method of testing piles. Such a standard should lay down the increments of load, the rate of applying and releasing the load, the points at which the load should be released and the permanent set measured, and the time for which each increment should remain on the pile. The latter might be related to the settlement.

A standard dolly and packing should also be used when driving piles which it was intended to test, so that comparison with results given by driving formulae would be simplified. It was not necessary, of course, for that dolly and packing to be used for driving all piles on a site.

The Authors preferred to apply the load directly to the top of the pile, but the use of a jack between the load and the pile had the advantage that experiments to a standard could be readily carried out. The disadvantage mentioned, namely, that constant attention to the jack was necessary, was not expensive compared with the total cost of a test.

Measurement of a settlement by means of graph paper fixed to the pile and by bars fixed to the ground was not generally satisfactory. Paper was affected by damp and the ground on piling sites was not usually good. In some experiments that Mr Cassidy had recently carried out, four white plastic scales had been fitted to arms cast in the pile, and had been read by two dumpy levels resting on pile heads a short distance away.

The level of the line of sight had been fixed very accurately by means of a mark on a plate fixed to the side of a pile. All four scales had been read by each instrument and the results had been averaged.

The Authors had given the results of tests on a long and on a short pile at the Keadby power-station site, and had stated that the short pile had failed. The driving records and borings indicated that the piles not founded on the Keuper Marl might not be satisfactory, but the settlements under a load of up to 120 tons had been very similar for both piles. The long pile had not been tested beyond that and it was only at a greater load that the short pile had commenced to settle rapidly. Increased settlement during a second test on the short pile was to be expected and had been found during other experiments. It would, therefore, be interesting to know why the Authors considered that the shorter pile had failed.

The Authors had described how measurement of temporary compression had been carried out, and if they would give figures of such measurements for the tests for which details of the strata were given, the value of the very interesting graphs and Tables in the Paper would be enhanced.

Mr J. Owen Lake, of Toronto, remarked that, despite the justifiable criticism of piling formulae in general, there was considerable evidence to show that the Hiley formula gave reliable results when used with appropriate corrections for such variables as type of packing under the pile helmet and type of dolly, and applied to piles driven into a bearing stratum of coarse-grained cohesionless soil, soft rock, or hard boulder clay. However, it was necessary to emphasize that neither the Hiley nor any other dynamic pile formula could give any indication whatsoever of the bearing capacity of piles deriving support from silts or clays having natural moisture contents appreciably greater than their plastic limits. Undoubtedly a lack of appreciation of that fundamental limitation of dynamic ground testing, when applied to cohesive soils, was still prevalent, although it had often been the subject of comment.

The Authors had stated that from a soil survey by means of boreholes it was possible to estimate the length of pile which would be required. However, to make such an estimate it was necessary to assume values for end-bearing and skin-friction, and the magnitude of possible errors in those assumptions was perhaps exemplified by the necessity for extending the length of the 50-foot test pile on the Doncaster site to 80 feet. Attention was therefore directed to the rapid development that had occurred in determining the required lengths of piles and assessing their ultimate bearing capacity by prior subsurface exploration with the Dutch deep-sounding apparatus.[1] Despite certain deficiencies (outlined by Mr Owen Lake in the discussion on Mr Huizinga's Paper) that required attention, the method was a noteworthy development and provided, for a wide range

[1] T. K. Huizinga, "Application of Results of Deep Penetration Tests to Foundation Piles." Bldg Res. Congr., 1951. Division 1, p. 173.

of soil conditions, the most rapid and the simplest means yet devised for determining the level to which piles should penetrate to give the most economical foundation. It had not replaced the necessity for test loading in certain soil conditions but if it was used to supplement borings it was possible to reduce the number of test loadings. Furthermore, the use of deep-sounding apparatus enabled a more detailed soil profile to be prepared and thereby reduced the risk inherent in the assumption that there was no marked variation in the sequence or strength of strata between boreholes.

On p. 45 it was stated, in connexion with the required length of piles, that "The driving and loading of test piles will then allow a closer assessment to be made, depending upon the amount of settlement which can be tolerated." That inferred that the test loading of a pile could indicate the settlement that would result after the structure had been erected. It was to be noted, therefore, that the settlement of a building on a pile foundation depended, among other factors, on the overall width of the foundation, and thus the behaviour under test of a single pile or even a group of piles gave no indication of the magnitude of possible settlements of the structure, especially if cohesive strata existed below the site. In addition, the driving and test loading of a single pile deriving support from cohesionless strata was not indicative of the ultimate load of a large group, because during the driving of closely spaced piles considerable compaction of the strata would occur and increased bearing capacity would thereby result. Thus whilst test loading was of value, it nevertheless had decided limitations and the interpretation of the results required experienced judgement.[2]

Referring to the Abadan S.P.A. site it was regretted that no boring details were given. In the absence of such information it was difficult to discuss the cause of the general settlement that had occurred after all the piles had been driven but before erection of the superstructures had started. However, since there had been practically no load on the piles at the start of the settlement, and the settlement pattern had been centred on the most heavily piled area located under the catalytic cracking plant, it appeared that remoulding of the soft clay during pile driving was the predominant cause. It was observed that the density of the piles under the chimney was less than in the area of the catalytic cracker where complete remoulding of the clay was most probable, and furthermore, the chimney was not located immediately adjacent to other piled areas. A further possiblity that could not be ignored was that the strata varied over the site and therefore publication of the boring logs together with the results of soil tests including the sensitivity of the clay would greatly enhance the value of the Paper.

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[2] J. Owen Lake, "Test Loading of Piles." Civ. Engng & Publ. Wks Rev., vol. 44, p. 674 (Nov. 1949).

The Authors had referred to the fact that whilst the soil around the test piles had reconsolidated within 1 to 2 months, subsidence of the area of the reactor-regenerator foundations had continued for 5½ months after all piles had been driven. That was to be expected, however, for the following reasons: the zone of remoulded clay involved when driving a single test pile extended only a short distance beyond the surface of the pile, and that disturbed soil derived support from the undisturbed soil surrounding it. In a large closely spaced pile group, however, the clay was almost completely remoulded within the group and the boundary of undisturbed clay was located a considerable distance outside the periphery of the group and below the level of the pile points. That had been demonstrated by model tests [3] and was confirmed by field observations. Therefore, because the clay was disturbed for a much greater depth below a group of piles than below a single pile, a correspondingly greater settlement was to be expected. Furthermore, the disturbed soil surrounding a single pile reconsolidated comparatively quickly owing to lateral migration of soil moisture caused by the highly compressed state of the soil immediately surrounding the pile. In a closely spaced group, however, the moisture content of the clay within the group could not escape laterally, except around the periphery of the group, hence the considerably longer period of time required to obtain equilibrium conditions.

Apparently there had been difficulties in finding a pile frame for the test piling and finally a 45-foot frame had been obtained and extended to enable a 60-foot pile to be driven. Had the limitations of that equipment resulted in adopting 60-foot piles for the permanent structures? If appreciably firmer strata had existed at a depth as great as 150 feet it would have been economical to install an alternative type of pile carrying a greater load per pile, provided of course that such an alternative pile had been readily obtainable. Furthermore, even if the soil was homogeneous to a great depth, the settlement of a floating pile foundation carrying a given load distributed over a given area decreased appreciably with increasing length of piles.

Finally, Mr Owen Lake observed that the object of test loading was to enable a more accurate assessment of the safe load to be deduced. It would therefore be of interest to know what criterion the Authors applied to their load-settlement diagrams to obtain the ultimate and the safe working loads.

Mr J. A. Maughan observed that most engineers would agree with the following statements which were somewhat similar to those made by the Authors:—

(1) Most piling formulae were inaccurate, even in the case of point

[3] G. P. Tschebotarioff and J. R. Schuyler, "Comparison of the Extent of Disturbance produced by Driving Piles into Plastic Clay to the Disturbance caused by an unbalanced Excavation." Proc. 2nd Int. Conf. Soil Mech. & Foundn Engng, Rotterdam, 1948, vol. 2, p. 199.

bearing piles, and they should not be relied upon in the case of friction piles.

(2) It was desirable to have test boreholes sunk on the sites of all major structures in order to determine the depth, the sequence, and the properties of the strata. That work should be done in the preliminary stages of the scheme.

(3) It was desirable to use a heavy hammer for driving piles.

The driving of test piles and the test loading of piles, however, should not be carried out until the final soil mechanics report on the site had been received, otherwise the results of the test loading might be rendered useless by the soil mechanics report. Sometimes the soil mechanics experts did not describe the strata correctly in the preliminary reports and there had been cases where the preliminary, the interim, and the final reports were quite different. In one case, a 16-inch-square ordinary reinforced-concrete pile with a penetration of 35 feet had had a permanent settlement of only $\frac{1}{16}$ inch after the test load of 130 tons had been removed. That test had been nullified by the soil mechanics report which had stated that there was a layer of soft clay below the strata into which the pile had been driven and that longer piles would have to be used to avoid the danger of differential settlement.

Piling hammers of 4 tons and 5 tons weight were quite common and heavier hammers had been used. An extract from a piling specification, issued in 1945, read as follows:—

> " Reinforced-concrete piles 16 inches square and 14 inches square or smaller section shall be driven with a piling hammer weighing not less than 4 tons and piles 18 inches square with a piling hammer weighing not less than 5 tons. The piling hammer in both cases being of a type to the approval of the Engineers. Driving operations shall in all cases continue until the penetration of the pile does not exceed 1 inch for six blows of the hammer, the energy for each blow being [as shown in the accompanying Table] "

Length of pile: feet	Energy per blow: foot-tons		
	14-inch-square piles	16-inch-square piles	18-inch-square piles
20 to 29	10	12	—
30 to 39	11	14	—
40 to 49	12	17	18
50 to 59	—	19	21
60 to 69	—	—	24

It was interesting to note that in the case of one type of prestressed

concrete pile, 12 inches square (stated to be equivalent to an ordinary reinforced-concrete pile 16 inches square), the manufacturers had specified that the maximum energy to be used when driving a pile was to be 9 foot-tons. Since the Authors believed in the use of heavy pile-driving hammers it was rather surprising that they should have specified a 2½-ton hammer for the driving of the 15-inch-square test pile at Doncaster. On p. 53 it was stated that four 16-inch-square precast reinforced-concrete test piles had been driven at Keadby power station, but the details in *Fig. 12* (*b*) gave the size as 14 inches square.

The Authors favoured the use of water jets in order to speed up the pile driving and in order to save the contractor's money (presumably the contractor would know the site conditions, the completion date for the contract, and his unit rates when tendering). There were, however, disadvantages with water jetting, such as the blocking of the jets by clay, a wet site, and the possible undermining of plant, etc. Also the piles would be about an average of 9 inches out of position and in order to comply with some specifications the contractor would have to withdraw practically all the piles and then re-drive them at his own expense. The Authors had stated that the contractor at Doncaster had not wished to use water jets and it should be noted that the use of water jets was abandoned at Uskmouth power station.

The Authors, in reply, were grateful to Mr Cassel for pointing out the error in the statement on p. 58 regarding the penetration of the normal reinforced-concrete and prestressed piles at Portishead; the penetration of the prestressed pile was the greater of the two as shown in Figs 17 and 18, Plate, 2 and the word "smaller" in the ninth line on p. 58 should read "larger." The results of the tests at Abadan had provided an excellent example of the limitations of loading tests on piles. However, the site conditions there had varied considerably and the Authors regretted that they had no space to give more details of the strata and soil tests. There was no systematic soil profile, in the sense intended by Mr Cassel, the boreholes revealing an alluvium subject to entirely random variation in its properties.

The Authors agreed with Mr Cassidy that it was preferable to adopt standard conditions for driving all test piles. However, in order to avoid delays it was sometimes necessary to use the plant which was readily available and it was regrettable that it was not normally practicable to extend pile tests over longer periods of time than those adopted in the tests described in the Paper. The Authors did not altogether agree with Mr Cassidy's statement that it was not necessary for the same standard type of dolly and packing to be used for the working piles and they thought that it was better to maintain exactly the same conditions as in the tests when driving the working piles; in practice, of course, it was often necessary to make changes.

It would be a most difficult matter to standardize equipment for

driving test piles, owing to the wide variation in the nature of the pile itself. A standard type of dolly might be used but the packing usually changed its characteristics as driving proceeded. That had been pointed out in the Paper.

As previously mentioned by the Authors, one disadvantage of a pure jack-loading test lay in the necessity for constant attention to the jack, but a further disadvantage was that one was completely dependent on the efficiency of the operator. The method of measuring the settlement of test piles by means of two dumpy levels was interesting; but in the Author's experience direct readings were very much better, especially when using dial gauges which gave a far greater degree of accuracy. At Abadan readings had been taken on the same pile by direct measurement and also with a dumpy level; but the latter method had proved considerably less reliable. After all, the accuracy of direct readings could always be checked by taking levels on the reference bar or rail before, during, and after the test to make sure that it has not been disturbed.

The Authors could not agree with Mr Cassidy's contention that the settlements of the long and short test piles at Keadby had been similar. It should be remembered that the long pile was 14 inches square and the short pile 16 inches square. The readings show both piles to be unsteady at 106 tons but the long one held at the next stage, 121·7 tons, whereas the short pile failed at 133·6 tons. In the latter case there was some doubt as to the accuracy of some of the readings and a second test was ordered. As Mr Cassidy had stated, that test showed increased settlement but again the Authors could not agree that it was to be expected. The element of time was important, so far as it affected reconsolidation of the ground. The Authors had had experience of subsequent tests giving either greater or less settlement for particular loads. Test-pile A at Abadan served as an example; settlement had decreased between the first and second loading (see Table 1, Plate 4). It might be added that the failure load remained fairly constant for the third and fourth loading at about 55 tons.

The complete driving records would occupy too much space to give here. They would include the measured temporary compressions other than those shown in Table 1, Plate 4, and Table 2 of Appendix II.

Mr Owen Lake had drawn attention to a test pile at Doncaster which had to be extended. As mentioned in the second paragraph of p. 57, that pile had been driven at a point where trial borings had shown a basin to exist. Piles longer than 60 feet required special pile-driving plant; thus if the number of long piles required was not great the extra costs of the transport and use of special equipment were not warranted and it was more economical to drive piles shorter than 60 feet in length and to extend these as necessary.

The Authors agreed that the results of tests on individual piles and small groups had to be interpreted with judgement backed by experience.

For that reason it was impossible to give a concise answer to Mr Owen Lake's enquiry about the criterion adopted in interpreting load-settlement diagrams. The allowable settlement depended on the type of structure, its function, the relation of live to dead loads, the variation in the live load and many other factors which made it impossible to apply any standard procedure. The only conclusive test was to check the settlement of the structure during erection and preferably for some years after completion. Such tests, if carried out with sufficient thoroughness, could provide an invaluable store of general data for use on future work. Until some more reliable method of assessing the safe load on a pile was found, the Authors were of the opinion that test piles made by far the most useful contribution to the information available to the designer.

Turning to Mr Maughan's remarks about the weights of pile hammers, the Authors certainly believed that the weight of the hammer should be related to the weight of the pile and that within certain limits the heavier the hammer the better. However, if a prestressed pile, 12 inches square, were substituted for an ordinary reinforced concrete pile, 16 inches square and of the same length, then a reduction in the weight of the hammer would be reasonable.

At Doncaster, the use of a 2½-ton hammer for test piles had not been specified, but it had been agreed to in order to suit the plant readily available. Most of the working piles had been driven with a 4-ton hammer.

The Authors did not understand why Mr Maughan had stated that they favoured water jets, nor his allusion to saving contractor's costs. The contractor normally asked whether he may use water jetting when he tendered and was permitted to do so if the engineer was satisfied that the ground was suitable and its supporting capacity would not be affected. The main point was to ensure good progress in the work. Certain disadvantages attendant upon jetting piles could exist but with adverse site conditions the use of jetting undoubtedly speeded up the progress and ensured uniform penetration to a required stratum, which was not always possible with closely spaced piles when using normal pile-driving methods.

CORRESPONDENCE

on a Paper published in Proceedings, Part I, July 1953

Paper No. 5922

"Modern Developments in Surveying Methods and Instruments" †

by

Alfred Stephenson, O.B.E., M.A., F.R.I.C.S.

Correspondence

Mr E. S. G. de la Motte, of Takoradi, Gold Coast, observed that the Author had rightly drawn attention to the extent and high quality of ground control required for really accurate contouring from air photographs, but unfortunately had touched only lightly on rough contouring to a vertical interval of 25 or 50 feet. In the present days of almost unlimited development in remote places, the engineer frequently looked to air photographs to help him in the initial stages of a project—both in the preparation of the preliminary estimates and in his first reconnaissance on the ground—and it was there that the need for rough contours was most pressing.

Reconnaissance for route surveys for either road or railway in bush or forest country represented a considerable proportion of work overseas at the present time.

The need was for a rough-contoured map of a strip of country about 5 miles wide at a scale of 4 to 6 inches to the mile with 25-foot vertical-interval contours correct to within about 10 feet, on which two or three alternative routes could be plotted for comparison and the best line for the preliminary survey proper determined.

Orthodox ground control for such a strip would normally be too costly to contemplate, but something better than the uncontrolled formlining now used—useful though it was—would be of great benefit; moreover, even rough formlining was difficult in thick forest where the ground was not visible on the photographs and the forest canopy was not uniform.

From time to time brief notices appeared of an Airborne Profile Recorder, and (even briefer) its use by an air survey company in Toronto.

† Proc. Instn Civ. Engrs, Part I, vol. 2, p. 380 (July 1953).

That gave by radar a ground profile of the centre line of each strip of photographs flown, similar to the sea-bed profiles obtained from an echo sounder, but the method would seem to depend too much on the accuracy of height determination of the aircraft.

It would be interesting to have the Author's views on the accuracy of the method and the possibility of distinguishing the ground echo from that of the tree canopy in forest country. If the method could be perfected, a great saving both in time and money would result.

Mr E. T. Haws suggested that many of the new techniques and instruments were beyond the accuracy required for normal civil works, but the news of the measurement of steel-band temperatures by resistance methods would be a comfort to any who had tried banding on a sunny day.

The Watts Microptic No. 2 theodolite described by the Author appeared to be a good new "one second" instrument, but Mr Haws's experience had all been with the Cooke, Troughton & Sims' "Tavistock" theodolite. He assumed that the test on the Watts' instrument had been carried out in near-laboratory conditions. The Author's statement that mean face-left and face-right readings for seventy-two measures of an angle had a total range of less than 3 seconds corresponded with a statistical system of determining observational accuracy used by Mr Haws for recent triangulations.

All the surveys had involved a series of braced quadrilaterals, often interlaced and highly redundant. Four mean face-left and face-right readings had been made of each angle, and the mean of those four had been the mean observed value of that angle. *Fig. 8* (*a*) was a frequency curve for the deviation of the four readings of an angle from the arithmetic mean of those four readings, for the Errochty dam triangulation. Mean observed values had been adjusted according to the theory of probability to suit the geometric conditions, and the adjusted figures had been so redundant that for the statistical analysis the adjusted angles had been assumed to be "true" angles.

The groups of readings of any one angle were samples of four of the universe of all survey results under similar conditions. The standard deviation of that universe was approximately the square root of the average variance within samples.

If $\bar{x}$ denoted the mean of four readings and x any individual reading,

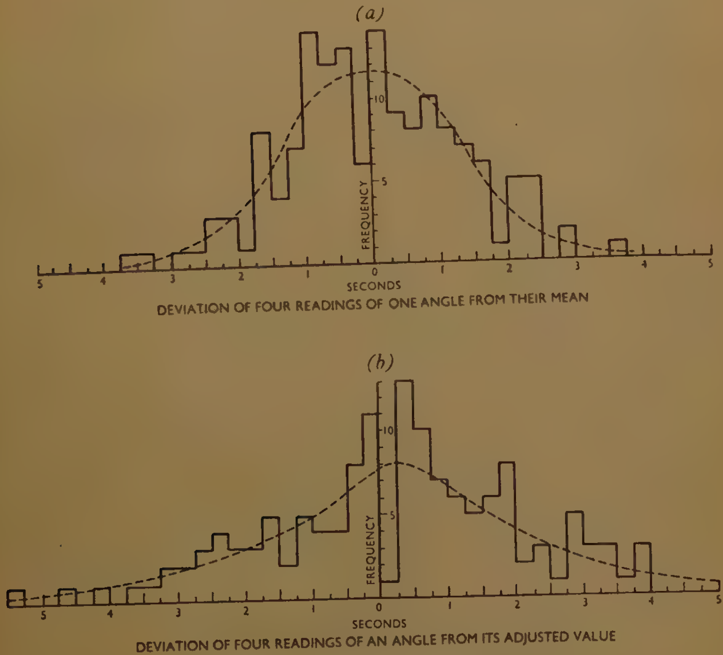
then $$s^2 = \frac{\Sigma(x-\bar{x})^2}{3}$$

where 3 was the number of degrees of freedom of the four readings, and s denoted the within-sample standard deviation.

The universe standard deviation σ was given by $\sigma^2 = \dfrac{\Sigma s^2}{n}$ where n denoted the number of samples.

The value of σ could thus be determined approximately at an early stage of a large survey, after the first few angles had been measured. An alternative method of finding an approximate value of σ was from the sample ranges. If the mean range of the first n samples was $\bar{w}$, then $\sigma \simeq \frac{\bar{w}}{d_n}$ where d_n was a tabulated constant varying with the number in the sample.

Figs 8



ERROCHTY DAM TRIANGULATION

The standard deviation σ was then used to see if the required accuracy was being maintained. With the same observers, instrument, and conditions it would remain constant as the survey proceeded. External causes affecting results at a station could often be spotted from the range of the four readings of the angles there. Tables for control-chart limit-lines for range gave the constants shown in Table 1.

With no assignable cause acting, the range of four readings of an angle could be expected to exceed $3{\cdot}98\sigma$ $(= D_{0{\cdot}975} \times \sigma)$ once in forty samples. Mr Haws had used that limit and when a greater range had occurred the conditions had been examined carefully. If no circumstance had arisen

TABLE 1

No. in sample	Lower limits		Upper limits	
	Outer $D_{0\cdot001}$	Inner $D_{0\cdot025}$	Inner $D_{0\cdot975}$	Outer $D_{0\cdot999}$
4	0·20	0·59	3·98	5·31

to recommend complete re-observation, the original reading furthest from the arithmetic mean had been re-observed.

Had the number of readings, m, in the samples been greater than 4, then the means of those samples would have been distributed with standard deviation $\sigma/\sqrt{m}$, the standard error. With known standard error the probability of the error of the sample mean exceeding certain amounts could be read from Tables. Hitherto surveyors had usually quoted "probable error," a term not in favour with statisticians, and not so easily handled as standard error.

The comparison of standard errors allowed a quick determination of the number of readings required under differing conditions to obtain a mean of equal weight with those obtained under the original conditions. On a recent survey one particular station had been much more exposed than the others, and the range of mean face-left and face-right readings had been excessive. The standard deviation, σ_1, of those readings had been found to be 1·6 times as great as that obtained elsewhere. In order to obtain the same standard error at the exposed station, the number of mean face-left and face-right readings required had been:

$$m_1 = \frac{\sigma_1{}^2}{(\text{normal standard error})^2}$$

which could have been reduced to $m_1 = 1{\cdot}6^2 \times m$ where $m > 4$.

In Mr Haws's particular examples the standard error could be found direct from the deviations of mean observed values of the angles from the finally adjusted values of those angles.

Fig. 8 (*b*) was a graph of deviations of four readings of an angle from its adjusted value for the Errochty dam survey, showing approximately Gaussian distribution. It would be noted that the curve was slightly asymmetrical with a peak towards the negative deviations. Owing to micrometer run error the expected average deviation on any angle was $+0{\cdot}05$ second; that was to say, if chance causes alone had been operating the peak of the frequency curve would be expected at a universe mean of $\mu = +\,0{\cdot}05$ second. In that case the mean $\bar{x}$ of thirty-six deviations of mean observed angles had been $-\,0{\cdot}25$ second. A test could be applied

TABLE 2

Survey	Date and time observed	Set up	No. of stations	No. of braced quadrilaterals	No. of angles measured	Average length of sight: feet	Target rod	σ by deviation of 4 readings from their A.M.: seconds	Average range of 4 readings $\bar{w}$: seconds	Approx. σ by $\bar{w}$: seconds	For four readings: $\sigma \times D_{0\cdot975}$: seconds	For four readings: Max. range allowed: seconds	Standard error: seconds
Errochty Dam	May 1950, before 9 a.m., after 6 p.m.	Wooden tripod on concrete base. Shelter round three sides	9	6	36	1,500	Machined steel rod, ½″ dia.	1·5	3·21	1·56	6·0	6	1·3
Glascarnoch Tunnel	January 1953, throughout day	Instrument screwed direct on concrete pillar	9	4	36	5,000	2″-dia. pipe	2·04	4·4	2·14	8·1	8	1·14
		Wooden tripod on ground, no shelter	7	3	14	5,000	1″-dia. ranging rod						1·15
Vaich Tunnel	February-March 1953, throughout day	Wooden tripod on ground, no shelter	14	12	51	6,500	1″-dia. ranging rod	2·23	4·6	2·23	8·9	8	1·12

to find if such a mean was significantly different from μ. Assuming no assignable cause, the deviation of $\bar{x}$ from μ in standard measure was:

$$u = \frac{\bar{x} - \mu}{\sigma/\sqrt{l}}$$

where l denoted the number of mean observed angles and σ the standard deviation of mean observed angles. In that case, $u = -1{\cdot}38$, and the probability of such a value occurring was 17 per cent. There was thus no evidence to suggest that the hypothesis of no assignable cause was false. In that way a test for suspected bias could be applied.

Table 2 showed the results of the statistical analyses of three surveys using the "Tavistock" theodolite. Two observers had worked on each survey, but one observer had been common to them all. There had been no detectable difference between the results obtained by the various observers, and so the only variables were the conditions under which the surveys had been made.

Mr Haws would welcome any similar information for different theodolites under working conditions.

Mr W. E. Blackmore felt impelled to answer a criticism of civil engineers made during the discussion. It was to the effect that civil engineers gave little help to manufacturers in developing new instruments by refraining from buying or, indeed, from showing much interest in the latest devices produced.

It was true that, whether by their own fault or the manufacturers' fault, civil engineers appeared to have little influence on the design of surveying instruments and that was evidenced by the fact that, of the many new developments in the instruments exhibited by the Author, few were of real use to the civil engineer as opposed to the cartographer.

An important principle from the civil engineering surveyor's point of view was that surveying time spent in the field was much more expensive, possibly as much as five times more, than time spent in the office on computing and plotting if account was taken of the size of the field survey party, expenses in accommodation and transport, time lost through bad weather and short winter days, and the use of costly instruments. In the design of surveying instruments and methods the emphasis should therefore be concentrated on saving field time if necessary at the expense of office time. Most of the devices described or exhibited appear to do the opposite. For instance, whereas a conventional vertical staff used for stadia work could be placed on the point being surveyed by an unskilled chainman and held vertically ready for a sight from the observer at the theodolite in a matter of seconds, it required a skilled surveyor minutes to erect a horizontal staff on its tripod ready for a sight. The auto-reducing devices were subject to the same criticism since they only saved a certain amount of office work at the expense of field time.

On the other hand, developments in other directions would be of

great use to the civil engineering surveyor and the following two were suggested :—

(*a*) A telemeter, or range-finder, with a theodolite type of mounting giving vertical and horizontal angles. Such an instrument would enable the surveyor to fix a number of points from one station by sighting on blades of grass, rocks, etc., without the need of a staff being held on the points; that would be particularly useful to survey a cliff face or some otherwise inaccessible terrain.

(*b*) A metal staff not liable to deterioration by water and embodying a spherical levelling bubble as a rigidly fixed integral part of it.

Certain useful features of some foreign-made instruments might also inspire British manufacturers, for example :—

(*a*) The compass theodolite in which the horizontal circle carried the compass needle and was free to orientate itself. That saved considerable time in the determination of the position of consecutive stations by the "leap-frog" method, as in levelling.

(*b*) The arrangement by which the lid of an instrument case could be fixed over the instrument without removing the latter from its tripod; that would make it possible to protect the instrument during a short shower without losing the setting.

The Author, in reply, observed that the question of the reliability of the Airborne Profile Recorder had been dealt with by him in the discussion,[1] and to those comments he would add only that the "recording" from a tree canopy—and from some sands—was not a very clear one, precluding therefore, any great degree of accuracy. Rather than using the A.P.R. in a densely tree-covered area, a better idea of the relative topography would probably be obtained by using a Multiplex instrument for strip plotting, with little or no control.

The description of what was needed, as given by Mr de la Motte, was a little misleading in the use of such terms as "rough-contoured" and "correct to within 10 feet." What he had actually prescribed amounted to a comprehensive survey of the area to the normal degree of accuracy at such a scale (that was, $\pm\frac{1}{2}$ the contour interval) and which would have cost a considerable amount by any means of survey. The orthodox control, referred to as too costly, would probably have amounted to a trio of height-control points every 6th or 7th pair of photographs, along alternate strips. In rough tree-covered country a reduction in the amount of orthodox control and the use of Multiplex stripping would probably give a better "form line" more than by relying solely on an

[1] Proc. Instn Civ. Engrs, Part I, vol. 2, p. 418 (July 1953).

A.P.R. for height control. The latter must, of course, have some ground-control identification points as well.

Mr Hawes' contribution was an interesting statistical analysis of his problem, but the Author personally had no knowledge of angular measurements, made with other makes of theodolite, having been treated in the same way. The methods of Wright and Heyford, which produced substantially the same results, were still accepted by surveyors as the standard practice.

Concerning Mr Blackmore's comments, the Author would repeat what he had stressed in the first few lines of the Paper—that the aim of surveying-instrument designers had been to get more accurate results with greater speed and with less effort than before. The time spent making observations with a glass-arc theodolite was infinitely much less than would be required with a " silvered circle " and the accuracy far greater.

The Author agreed about the tediousness of setting up a horizontal staff, but Mr Blackmore would be glad to know that the Ordnance Survey were now using their new duralumin vertical staff for tacheometric work and were achieving results comparable with those obtained with the horizontal staff.

The Author hoped, with Mr Blackmore, that in the not-too-distant future, some form of precisely divided duralumin staff would supplant the wooden models.

Range finders that had sufficient accuracy for engineering purposes and at the same time were in any way portable, had yet to be designed. The method was such a convenient one that had the desired accuracy been attainable, range finders would undoubtedly have been developed for surveying engineering projects. In the meantime, if a survey of a cliff face was required with the minimum amount of field work, the answer would be to do it by ground photogrammetry.

OBITUARY

JOSEPH NEWELL REESON, who died at Melbourne, Australia, on the 15th July, 1953, was born on the 2nd June, 1868.

He received his early education at Kensington Grammar School and, as a young man, joined the staff of the Gas Light and Coke Co. at their Beckton works, continuing his education at the City of London College. He became in turn Engineer to the St Pancras works, in 1903, and to the Shoreditch works, in 1905, and was in 1906 appointed Resident Engineer of the Beckton works of the Gas Light and Coke Co.

In 1913, he went to Australia to take up the position of Engineer-in-Chief and Technical Adviser to the Metropolitan Gas Co. of Melbourne, and continued there until 1926. During this time he introduced electric welding into the construction and maintenance of gas-works plant, and by erecting constructional workshops made the company self-contained. In 1916, he represented the Government of New South Wales in the matter of the resumption by the Sydney Harbour Board of the Gas Light Company's Kent Street works.

Mr Reeson was elected an Associate Member in 1894, and was transferred to the class of Member in 1914. He was a Member of Council from 1939 to 1942, as the representative of Australia. He was also a Member of the Institution of Engineers, Australia, and of the Institution of Gas Engineers. Mr Reeson was one of the founders of the Allied Societies Trust, formed to provide a common home for some of the scientific societies of Victoria, and was chairman of the directors of the Trust from its inception until a year or two before his death.

In 1926, he was awarded a Telford Premium by the Council of the Institution for his Paper on "The Influence of Electric Welding in the Design and Fabrication of Plant and Structures."[1] He was also one of the first recipients of the Kernot Memorial Medal, awarded by the University of Melbourne, in 1929, for research into electric welding.

SIR BERNARD D'OLIER DARLEY, C.I.E., who died at Hindhead, Surrey, on the 11th August, 1953, was born on the 24th August, 1880. He was educated at Trinity College, Dublin, and at the Royal Indian Engineering College, at Cooper's Hill, Surrey.

In 1903, he was appointed Assistant Engineer to the Irrigation Branch of the Public Works Department in the United Provinces, India. Between 1909 and 1919, as Executive Engineer, he surveyed, designed, and built the Mirzapur canal systems.

[1] Min. Proc. Instn Civ. Engrs, vol. 222, p. 158 (1925–26, Pt 2).

In 1919, he became Superintending Engineer, and in 1924, Chief Engineer and Secretary to the United Provinces Government, and held this post until 1931. During this time, he was engaged in the design and construction of the Sarda Canal, and for his Paper [1] on this work he was awarded a Telford Gold Medal and Indian Premium by the Council of the Institution.

From 1932 until his retirement from the engineering service in 1937, he was Chief Engineer of Bahawalpur State, in Punjab. He later acted as a technical adviser to the Home Office in connexion with the organization of the Air Raid Precautions Department.

Sir Bernard was made a Companion of the Order of the Indian Empire in 1919, and was knighted in 1928.

He was elected an Associate Member in 1906, and was transferred to the class of Member in 1931.

He is survived by his wife, and by two sons and two daughters of a former marriage.

[1] "The Design and Construction of the Sarda Canal." Min. Proc. Instn Civ. Engrs, vol. 233, p. 140 (1931–32, Pt 1).

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